DEVELOPING OPTIONS

AN OVERVIEW OF EFFORTS TO SOLVE AGRICULTURAL DRAINAGE AND DRAINAGE-RELATED PROBLEMS IN THE SAN JOAQUIN VALLEY

DECEMBER 1987

San Joaquin Valley Drainage Program

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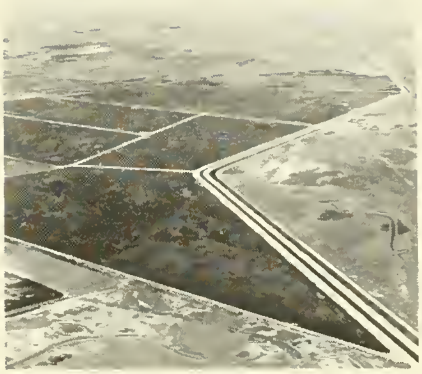


Introduction

The discovery in 1983 of migratory-bird deaths and deformities linked to high selenium levels in agricultural drainage water at Kesterson Reservoir focused national attention on drainage and drainage-related problems in California's San Joaquin Valley. Almost immediately, questions were raised such as — Are problems like these occurring elsewhere? If they are, can other situations like Kesterson be prevented? The San Joaquin Valley Drainage Program was created to help resolve the selenium issue and to address the long-standing problems of soil salinity and poor drainage of agricultural land as well as loss of fish and wildlife habitat in the valley.

This report provides a brief overview of valley drainage and drainage-related problems, the planning process being used to formulate and evaluate solutions, and management options being considered. It also covers some of the major findings to date and questions remaining to be answered before the Drainage Program concludes in September 1990. The report is intended to inform a broad audience, ranging from legislators to affected San Joaquin Valley citizens, about agricultural drainage and related problems and what is being done to solve them. It is not intended to provide technical details on the results of investigations or to present plans for drainage management. Reports on technical areas of investigation and analyses such as drainage-water treatment, reuse, and disposal; geohydrologic research; and fish and wildlife studies are scheduled for publication by mid-1988. A comprehensive report which presents management options and preliminary alternative plans is also scheduled for completion in 1988. A draft report outlining latest study results and alternative plans will be completed for public review in the fall of 1989. Final study results and recommended area-specific plans will be presented in a final report in the fall of 1990.

Because of the complexities involved, drainage and drainage-related problems will not be solved by any one organization or individual working alone. The Drainage Program conducts technical investigations, identifies and evaluates possible management measures, and provides coordination of drainage and related studies and activities being conducted by a large number of individuals and public and private organizations. On an ongoing basis, the Program works with many of these interests, including county health officers, growers, field geologists, laboratory researchers, water district managers, fish and wildlife biologists, and legislators and policy analysts in Sacramento and Washington, DC.

The Drainage Program is considering a broad range of both structural and nonstructural options to help solve valley drainage and related problems. The development of these options into alternative plans is designed to provide solutions that

will be economically, environmentally, socially, and politically acceptable.

Program Purpose, Goals, and Concerns

The San Joaquin Valley Drainage Program was established in mid-1984 by then-Secretary of the Interior William Clark and California Governor George Deukmejian. The purpose of the Program as outlined in a July 24, 1984 statement by Secretary Clark is to conduct "comprehensive studies to identify the magnitude and sources of the (drainage) problem, the toxic effects of selenium on wildlife, and what actions need to be taken to resolve these issues." The statement further noted that: "Early action on the selenium problem is critical and is directly related to the ultimate question regarding the disposal of agricultural drainage water in the San Joaquin Valley from over 500,000 acres of irrigated lands."

Consistent with the initial purpose, the goals of the Program are to identify measures to help solve immediate drainage and related problems and to develop comprehensive plans for long-term management of those problems. Four principal concerns being addressed by the Program in problem analysis and plan formulation are: (1) Agricultural productivity, (2) fish and wildlife resources, (3) water quality, and (4) public health.

Agricultural concerns focus on high salt concentrations and inadequate drainage of subsurface water, which impair the multibillion-dollar farming industry in the valley. Concerns about fish and wildlife relate to drainage-water contamination of now scarce fish and wildlife habitats and adverse effects on birds, fish, and other water-dependent wildlife. Agricultural drainage and disposal can result in degradation of water quality, posing a threat to other beneficial uses of both surface- and ground-water supplies. Public health concerns involve potential health risks that may be associated with elevated levels of contaminants such as selenium and other trace elements in agricultural drainage water and the wildlife food chain.

Program Scope and Funding

Policy direction of the interagency effort is designed to recognize State and Federal responsibilities of each of the five principal participating agencies: the California Department of Fish and Game, California Department of Water Resources, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and U.S. Geological Survey.

In addition to the Program's primary mission of developing solutions for drainage and drainage-related problems in the San Joaquin Valley, the results of Program research will contribute to related major policy decisions serving needs at local, State, and Federal levels. As examples, Program findings will contribute to:

- Development of plans to meet drainage water management needs of water districts in the Federal water service area as an alternative to completion of the San Luis Drain.
- Establishment/revision of water-quality objectives for the San Joaquin River Basin and the Sacramento-San Joaquin Delta by the State Water Resources Control Board and regional boards.
- Definition and solution of agricultural drainage and drainage-related problems throughout the western United States being investigated by the Department of the Interior's National Irrigation Drainage Program.

Program and related research activities are funded through both Federal and State appropriations. **Figure 1** shows approximate expenditures by Program category and the proportion of Federal and State funding for fiscal years 1986 and 1987.

Primary Federal funding for Drainage Program studies is through annual Congressional appropriations to the U.S. Bureau of Reclamation for the San Luis Unit of the Central Valley Project (as authorized by Public Law 86-488, June 3, 1960; amended by Public Law 95-46, June 15, 1977). Research, investigations, and activities being conducted by the Drainage Program under the San Luis Unit authority are summarized in **table 1.**

Additional Federal funds are provided for Program-related research under agency-specific authorities of the U.S. Fish and Wildlife Service and the U.S. Geological Survey (for example, the Service's national research program on migratory-bird diseases and contaminants and the Survey's Regional Aquifer Systems Analysis program).

During the period January 1985 to October 1987, some \$20.5 million in Federal funds (\$4.5 million, \$7.5 million, and \$8.5 million for fiscal years 1985, 1986, and 1987, respectively) was spent on Program research and activities under the San Luis Unit authority. The Department of the Interior is currently determining appropriate repayment terms, conditions, and beneficiaries for these Federal Program costs as required by Reclamation law.

State studies are funded primarily through the Selenium and Other Trace Elements in California Program, administered by the State Water Resources Control Board, and the annual budgets of the Department of Fish and Game and the Department of Water Resources.

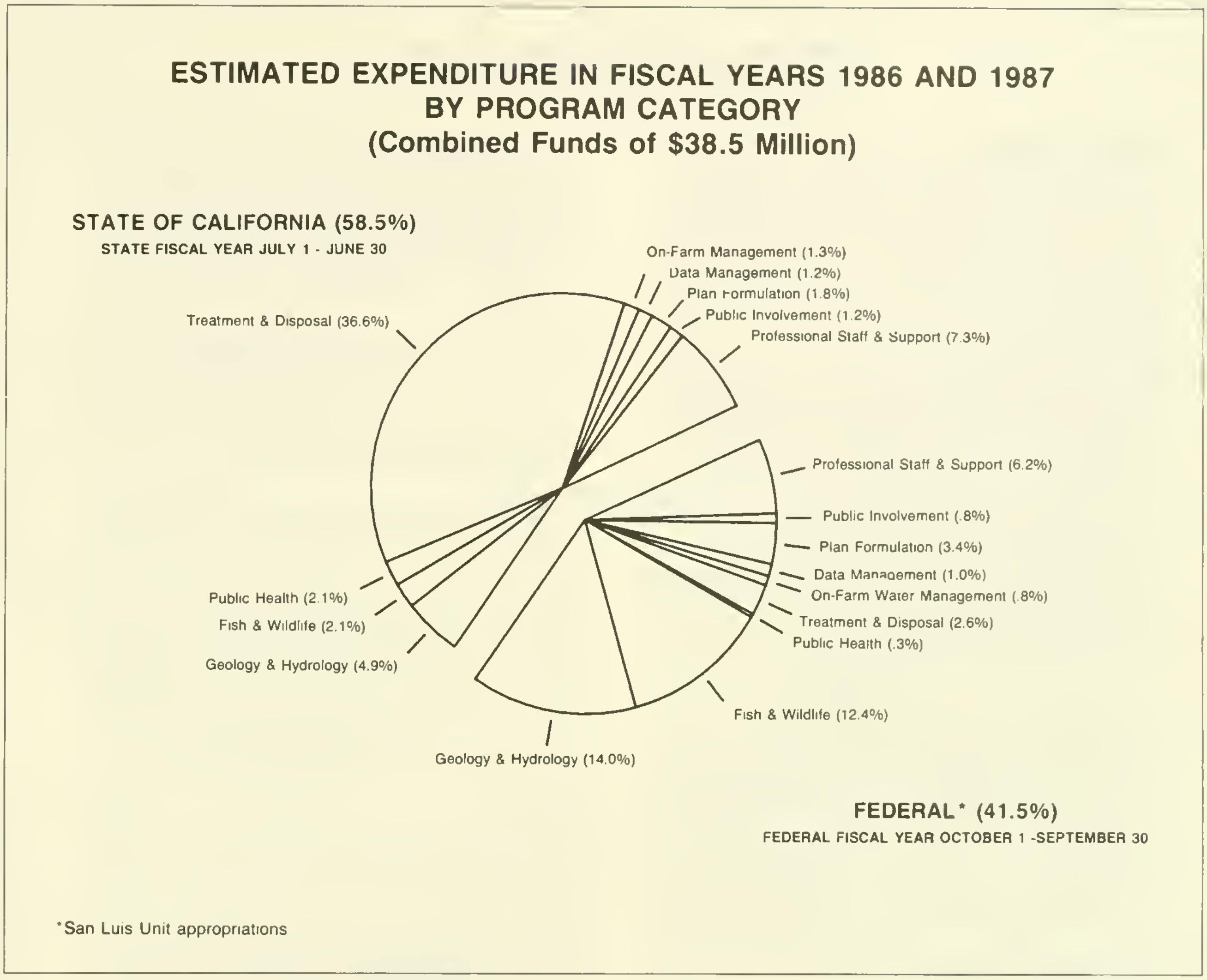


FIGURE 1

Program Organization

Specific guidance on Program direction and priorities is provided by a Policy and Management Committee, composed of the State, Regional, or District Directors of each of the five lead agencies: California Department of Fish and Game, California Department of Water Resources, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and U.S. Geological Survey. A full-time, interdisciplinary staff (Study Team) made up of personnel from these same five agencies is responsible for coordination, investigative, and planning activities.

The Program utilizes a wide range of technical consulting services and advisory committees. Universities, local governments, special-interest groups, and private citizens provide assistance and diverse perspectives, and serve an important role in the Program. (The Committees and Teams organized for the Program and their members are listed at the front and back of this report.)

Relationship to Other Programs and Activities

The Drainage Program coordinates closely with a number of agencies and organizations participating in research and investigations concerning drainage-related problems. Principal among these are: Selenium and Other Trace Elements in California Program, under the direction of the State Water Resources Control Board; University of California Salinity/Drainage Task Force, administered by the Division of Agriculture and Natural Resources; Kesterson Program, conducted by the Bureau of Reclamation; and Department of the Interior National Irrigation Drainage Program. Drainage-related research, investigations, and activities under way in addition to the Drainage Program are summarized in **table 2.**

San Joaquin Valley Drainage Program
Research, Investigations, and Activities

Geology and Hydrology
- Survey selenium sources
- Evaluate valley-wide ground-water quantity and quality
- Evaluate and model (for predictive purposes) ground-water quantity, quality, and movement in the Panoche Fan/Cantua Fan, including solute transport
- Document and evaluate shallow ground-water quantity and quality on a regional and local scale
- Conduct demonstration project for drainage flow reduction at selected valley sites

Fish and Wildlife
- Determine the geographic extent, nature, and severity of drainage-water contamination of fish, wildlife, and their habitats
- Identify substances of concern (their various chemical forms and compounds), safe levels, and toxic levels of each for fish and wildlife
- Describe bioaccumulation and biomagnification of selenium and other drainage-water contaminants in fish and wildlife food chains
- Identify synergistic, antagonistic, and other chemical interactive effects of substances of concern on fish and wildlife
- Identify fish and wildlife restoration, mitigation, and enhancement needs and opportunities
- Develop and evaluate alternative plans to address agricultural drainage-related fish and wildlife problems

Public Health
- Evaluate potential public health risks associated with agricultural drainage water
- Survey food consumption patterns of various local population groups and the general population outside the immediate drainage problem area
- Evaluate results of drainage water, ground water, and air quality monitoring and surveys of food products, livestock, and wildlife
- Evaluate toxicity exposure routes, exposure limits, and indicators of substances of concern

Treatment, Reuse, and Disposal
- Evaluate drainage water treatment processes including bacterial, iron filing adsorption, iron hydroxide, algal-bacterial, selective resins, volatilization, chemical-physical attenuation, and membrane separation (reverse osmosis)
- Evaluate potential reuse of agricultural drainage water for municipal and industrial supplies, power production, aquaculture, silviculture, fish and wildlife uses, and recreation
- Screen and evaluate potential drainage water disposal sites. Sites being considered include evaporation ponds, deep-well injection, and discharge to the San Joaquin River consistent with water-quality objectives

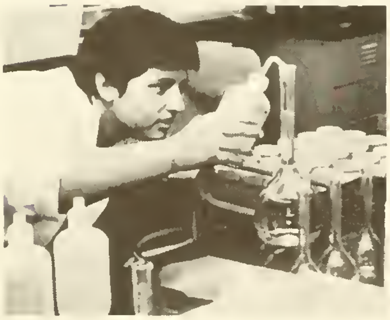
On-Farm Water Management
- Evaluate on-farm water management practices to reduce the total volume of valley drainage water
- Evaluate alternative on-farm water management scenarios
- Develop action plan for on-farm water management with timelines for short-term (0-2 years), intermediate (2-5 years), and long-term (5-10 years) implementation (ITAC Agricultural Water Management Subcommittee)

Data Management
- Develop computerized data base to help integrate, analyze, and apply Program data and related information
- Develop geographic information system (GIS) for mapping and analysis
- Conduct quality assurance/quality control program for water-quality sampling and for laboratory work

Plan Formulation
- Conduct economic studies on management of drainage-water residuals and develop local and regional-scale agricultural production models
- Conduct studies to determine economic and social factors that affect adoption of on-farm water conservation technologies
- Estimate consumptive and non-consumptive economic values of fish and wildlife resources
- Compile baseline data on valley socioeconomic conditions
- Assess the effects of existing laws, regulations, and policies related to drainage issues, and identify potential modifications to these laws, regulations, and policies
- Develop analytical models and procedures for evaluating management options and alternative plans

Public Involvement
- Conduct public meetings and workshops on Program studies and activities to solicit public input
- Provide informational materials to increase public understanding of drainage and drainage-related problems and possible solutions
- Provide an effective means to communicate with the broad spectrum of organizations and individuals interested in and affected by drainage and drainage-related problems (Citizens Advisory Committee)

Professional Staff and Support
- Provide scientific oversight of Drainage Program research and investigations (National Research Council Committee on Irrigation-Induced Water Quality Problems and subcommittees)
- Provide expertise and advice on technical aspects of the Program and review of technical material (Interagency Technical Advisory Committee and subcommittees)
- Formulate and evaluate short- and long-term drainage water management options, develop long-range alternative plans, and coordinate research and investigative activities (Interagency Study Team)



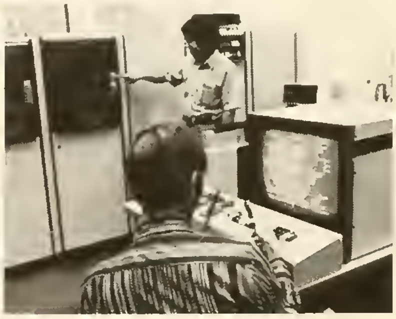


TABLE 1

Additional Drainage-Related Programs and Activities

State Water Resources Control Board

Selenium and Other Trace Elements in California Program:[a]

- Survey selenium sources
- Prepare historical report on selenium
- Develop criteria to protect beneficial uses of water
- Develop regulations for evaporation ponds
- Develop San Joaquin River water quality and quantity model
- Administer 1986 Water Conservation and Water Quality Bond Law

CA Regional Water Quality Control Boards

- Update water-quality control (basin) plans

CA Department of Fish and Game

- Conduct Toxic Substances Monitoring and State Mussel Watch Programs
- Conduct Selenium Verification Program — sampling in waters of potential concern (Salton Sea, San Francisco Bay, San Joaquin Valley)
- Analyze samples of water and fish and wildlife tissue

CA Department of Water Resources

- Conduct desalting research and demonstration
- Monitor San Joaquin River and Delta water quality
- Modify Grasslands water distribution system
- Develop guidelines for evaporation ponds
- Investigate selenium-removal technologies
- Provide irrigation management assistance
- Monitor contaminants in California Aqueduct
- Develop salt management program in the San Joaquin Valley
- Administer 1986 Water Conservation and Water Quality Bond Law

CA Department of Food and Agriculture

- Evaluate selenium levels in crops and animals
- Conduct agroforestry research and develop demonstration project

CA Department of Health Services

- Survey selenium and human health in California
- Issue health hazard warnings in areas of concern
- Survey San Joaquin Valley drainage water exposure
- Develop human contaminant toxicological profiles

University of California

Salinity/Drainage Task Force

- Survey sources and distribution of salts and trace elements
- Study hydrology and transport of salts and trace elements
- Study trace-element chemistry
- Study bioavailability and bioaccumulation of contaminants in wildlife food chain and crops
- Conduct crop salt tolerance and breeding tests
- Provide irrigation, drainage, and salinity management assistance

Lawrence Berkeley Laboratory

- Characterize hydrological, geochemical, and ecological processes and resources of Kesterson Reservoir

California State University, Fresno

- Evaluate reverse-osmosis pretreatment
- Study agroforestry effects upon wildlife
- Investigate removal of DBCP and other pesticides from ground water
- Provide on-farm management assistance

US Agricultural Research Service

- Conduct research and demonstration of irrigation and drainage methodologies
- Develop irrigation and drainage-related data base
- Advise local water districts and farmers regarding irrigation and drainage methodology

US Bureau of Reclamation

- Clean up Kesterson Reservoir
- Monitor water quality
- Develop plans for alternative water conveyance facilities for the southern San Joaquin Valley
- Investigate alternative water supplies for wildlife refuges and private wetlands
- Evaluate alternative water pricing and marketing policy for Federal water supplies

US Fish and Wildlife Service

- Conduct field surveys of agricultural drainage water contamination of biota in the Tulare Lake Basin
- Study ecological characteristics, biological activity, and migratory-bird use of evaporation ponds in Tulare Lake Basin
- Study effects upon disease resistance of migratory birds' exposure to agricultural drainage water contaminants in evaporation ponds
- Conduct field assessment of bluegill reproductive success in waters receiving agricultural drainage
- Issue endangered species lists
- Review and comment on permit actions related to agricultural drainage (evaporation ponds, treatment plants, discharges, etc.)
- Provide technical assistance to private wetlands owners/managers regarding management in contaminated environment

US Geological Survey

- Evaluate water-quality changes in San Joaquin Valley ground-water supplies as part of Regional Aquifer System Analysis (RASA)
- Monitor San Joaquin River flow and water quality as part of National Stream Quality Accounting Network (NASQAN)

US Soil Conservation Service

- Develop plans for disposal of subsurface drainage water from the South Fork Kings River area
- Evaluate agroforestry as a means of disposal of agricultural drainage water
- Advise local farming interests on irrigation and drainage-related problems including design of systems

Local Water Districts

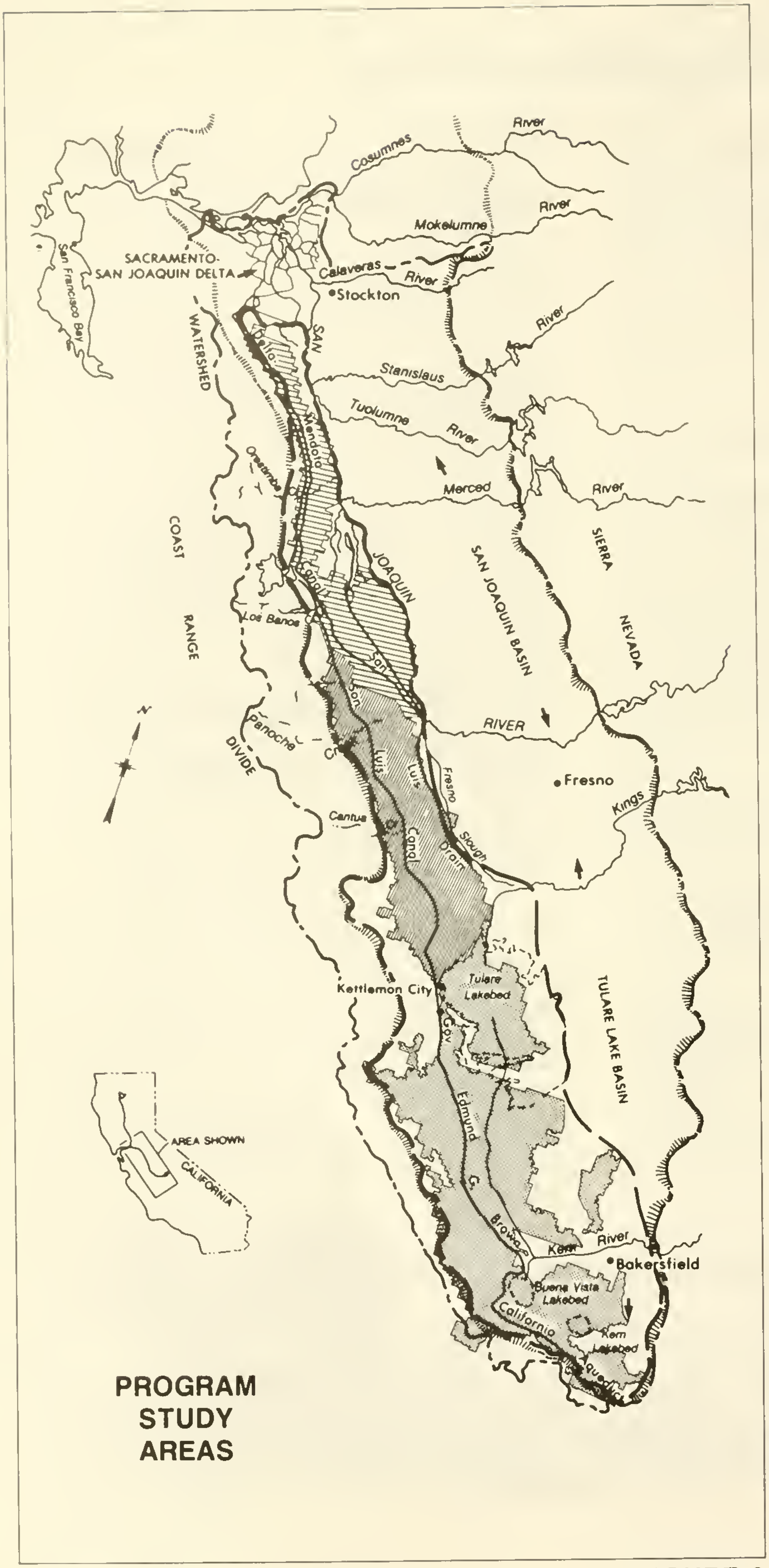
- Conduct demonstrations of drainage water treatment and disposal, including biological treatment and deep-well injection (Westlands Water District) and selenium adsorption using iron filings (Panoche Water District)
- Evaluate and promote use of state-of-the-art irrigation and water reuse-related technology
- Evaluate possible institutional entities to represent landowners and irrigation and drainage managers within the drainage problem area

US Department of the Interior National Irrigation Drainage Program

- Identify and evaluate agricultural drainage-related problems throughout the Western United States

[a]The Selenium and Other Trace Elements in California Program was established in 1985 by the State Legislature to complement other ongoing drainage-related programs, on a statewide basis Principal participants are SWRCB, DFG, DWR, and UC Salinity/Drainage Task Force.

TABLE 2



Study Area

Figure 2 shows the Drainage Program study areas, including the State and Federal water project service areas. The **general** study area includes the entire San Joaquin Valley, from the drainage divide of the Coast Range to the foothills (1,000-foot elevation) of the Sierra Nevada. The valley is divided roughly in half by the San Joaquin and Tulare Lake drainage basins.

The **principal** study area comprises those lands that are currently affected by problems related to agricultural drainage, as well as lands likely to be affected in the future. Most of these lands are located on the west side of the valley and include the State and Federal water project service areas.

Some ecological, hydrological, and economic factors outside the valley influence understanding of valley systems. To the extent that other areas affect or are affected by valley drainage and related problems and potential solutions, they are within the scope of the Program. Examples of such areas include the Bay-Delta region, the Pacific Flyway for migratory birds, and State, national, and world markets for valley agricultural products.

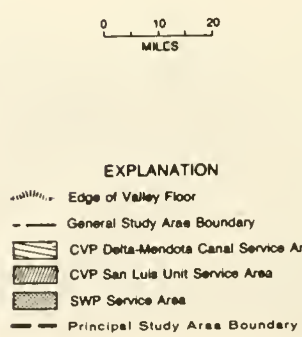


FIGURE 2

Drainage & Drainage-Related Problems & Conditions

Origin of Drainage Problem

Large-scale irrigation in the San Joaquin Valley began in the 1870's, and as early as 1886 a widespread need for drainage to sustain irrigated agricultural development was apparent. During the 1890's and early 1900's, extensive acreage was forced out of production as a result of salt buildup and waterlogging caused by inadequate drainage. Most of this land was subsequently returned to agricultural production by changes in cropping patterns and lowering of the water table through ground-water pumping for irrigation. As more lands were irrigated and pumping increased, however, ground water was used faster than natural recharge could replace it. Declining water levels required deeper wells, resulting in higher pumping costs and extensive land subsidence.

During the 1920's, California developed the State Water Plan, which outlined a massive project of dams, canals, and other structures to transfer water from northern California to water-deficient areas in the San Joaquin Valley. Although the project was authorized by the State legislature and approved by the voters in 1933, the nationwide economic depression prevented sale of financing bonds. The Central Valley Project was then authorized by Congress for Federal construction by the Bureau of Reclamation. Initial features of the CVP were completed in the 1940's, and the first project water was delivered to the San Joaquin Valley in the early 1950's.

Continued expansion of agriculture in the San Joaquin Valley and rapid population growth in the State following World War II led to development of additional water facilities. The San Luis Unit of the CVP and California's State Water Project were both authorized in 1960. The San Luis Unit provides irrigation water to lands in the northwestern part of the valley; the SWP delivers irrigation water to lands in the southern part of the valley. Together, the State and Federal projects provide an annual firm supply of about 3.6 million acre-feet of imported water to agricultural lands in the western and southern valley.

Plans for both the State and Federal projects included a joint-use master drain to serve the agricultural drainage needs of the entire valley. Subsequent events, however, prevented development of a master drain, and in 1968 the Bureau of Reclamation proceeded with construction of a drain to serve just the Federal project lands. The San Luis Drain was to extend 209 miles, from Kettleman City to a discharge point in the western Delta. Between 1968 and 1975, about 85 miles of the drain and the first stage of Kesterson Reservoir were constructed. Kesterson Reservoir was planned as an interim storage and regulating facility for flows from the San Luis Drain, and secondarily as wildlife habitat. When construction of the drain was stopped in 1975, Kesterson Reservoir became the

drain terminus. Beginning in 1978, the reservoir ponds served as a storage and evaporation facility for subsurface drainage flows from irrigated lands within Westlands Water District.

Following discovery of selenium contamination at the reservoir, the San Luis Drain and Kesterson Reservoir were closed to drainage use. The Bureau of Reclamation is currently working on the cleanup of Kesterson.

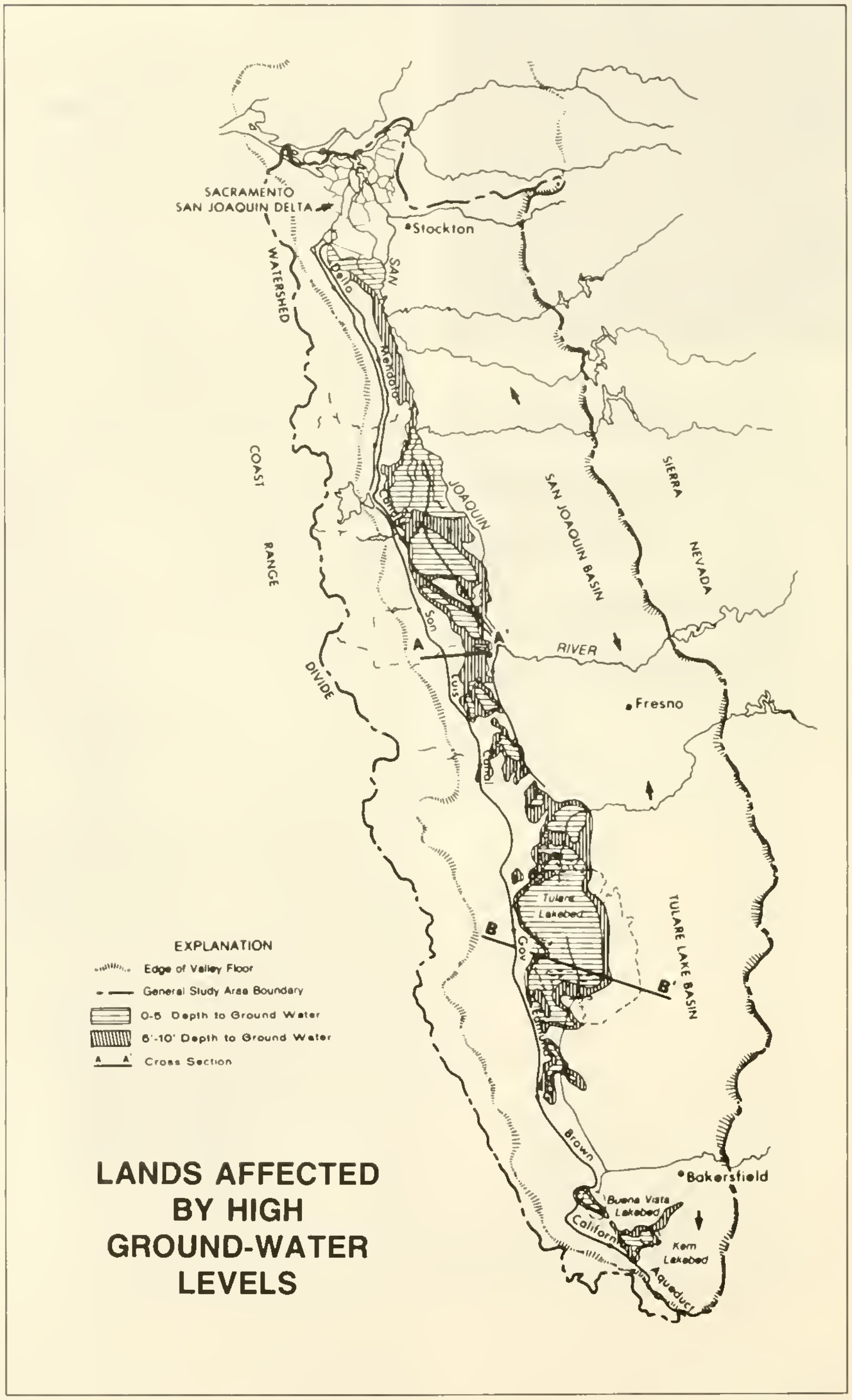
Salinity, Drainage, and Agricultural Productivity

The climatic characteristics of the San Joaquin Valley make it one of the world's most productive and versatile agricultural areas when adequate water supplies are available. Yields for most irrigated crops are uniformly and consistently high, exceeding national averages by wide margins. No other part of the country produces such a wide variety of crops in such abundance. Over 200 different crops are grown commercially, with at least 125 of these contributing significantly to the food supply and economy of the area, State, and Nation. Five San Joaquin Valley counties, all of which receive irrigation water from the State or Federal water projects, are among the Nation's ten highest producers of agricultural commodities in terms of gross crop value.

Irrigated agriculture provides economic stability for the western valley that is unmatched in agricultural regions that rely solely on natural precipitation for their water supply. Irrigated farming provides much greater uniformity in quality and quantity of production, allows a greater variety of crops, allows greater adaptability to change in market demand for crops, and assures greater yield per acre.

The regional economy of the western valley is dominated by agricultural production and related activities. Related activities include poultry and dairy processing, grain milling, cotton ginning, processing of animal feeds, fruit and vegetable processing, produce transportation, and retailing. Thus, any change in agricultural production can magnify economic effects on the region.

Approximately 500,000 acres of west-side agricultural lands are currently affected by ground-water levels that have risen to within 5 feet or less of the land surface due to irrigation. The geographic extent of high water-table conditions is shown in **figure 3.** High ground-water levels



LANDS AFFECTED BY HIGH GROUND-WATER LEVELS

FIGURE 3

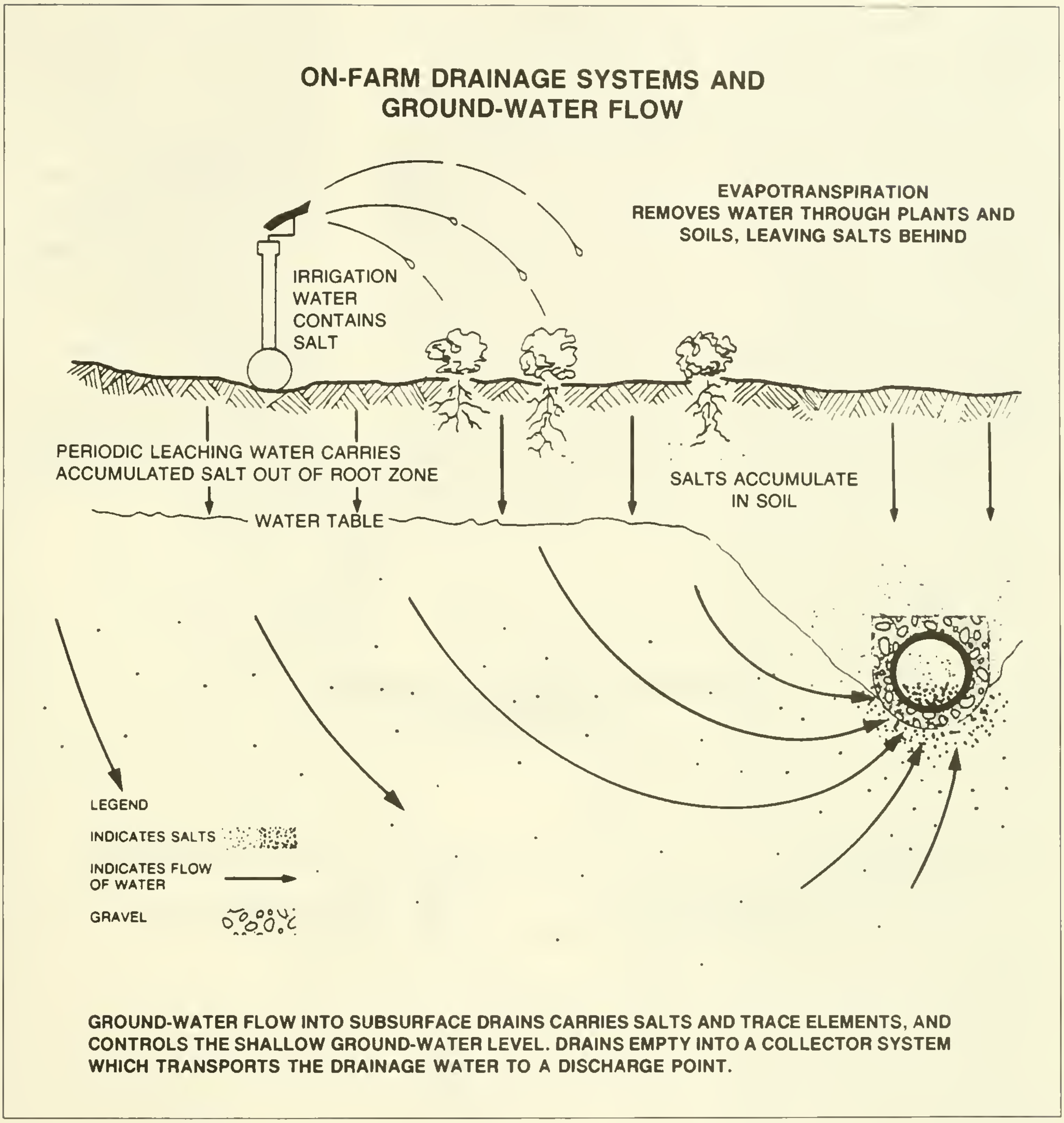


FIGURE 4

damage agricultural crops by depriving crop roots of needed oxygen and concentrating salts in the root zone. **Figure 4** shows how salts build up in the soil as a result of irrigation and evaporation and how subsurface drains are used to help remove the salts and control ground-water levels.

In some areas, subsurface flows from upslope irrigated lands may compound drainage problems for downslope areas. Some downslope growers have reported rising ground-water levels and increased subsurface flows coinciding with irrigation of upslope fields that do not have subsurface drains. The hydrologic interconnection between upslope and downslope lands is being investigated through Program studies.

Impacts on Fish and Wildlife

In the late 1800's, the combined Sacramento and San Joaquin Valleys contained approximately 4 million acres of wetlands and about 1 million acres of riparian forests. By 1950, most of the original fish and wildlife habitat in the San Joaquin Valley had been

converted to agricultural use, with some urban use. Wetland losses in California (1850-1977) are shown in **figure 5**.

Establishment of Federal refuges and State management areas in the valley, as well as private wetlands and hunting areas, has helped to preserve the remaining wetland and grassland habitats. These areas, shown in **figure 6**, provide important migratory and wintering habitat for millions of birds of the Pacific Flyway as well as year-round habitat for resident fish and wildlife.

The Grasslands area today, a remnant of the wetland, grassland, and riparian habitat that once occupied much of the valley floor, reflects many of the problems affecting fish and wildlife habitat in the valley. During the last 3 decades, half or more of the water supply for the Grasslands has been provided by subsurface agricultural drainage. In 1985, State and Federal biologists recommended that subsurface drainage water no longer be used for wetland management in the Grasslands area because of high concentrations of potentially harmful elements, such as selenium and boron, in these waters. Since that time, temporary water supplies have been arranged through local water districts to help replace some of the drainage water supply previously used in that area. However, the remaining habitat for migratory birds and other wildlife is expected to be significantly reduced unless a firm supply of good-quality water is made available.

Identification of alternative plans to supply the water needs of fish and wildlife areas impacted by agricultural drainage is an important concern of the Drainage Program. Previous water supplies (late 1970's — mid-1980's) and current water needs for optimum management of the valley's principal Federal and State wildlife areas (approxi

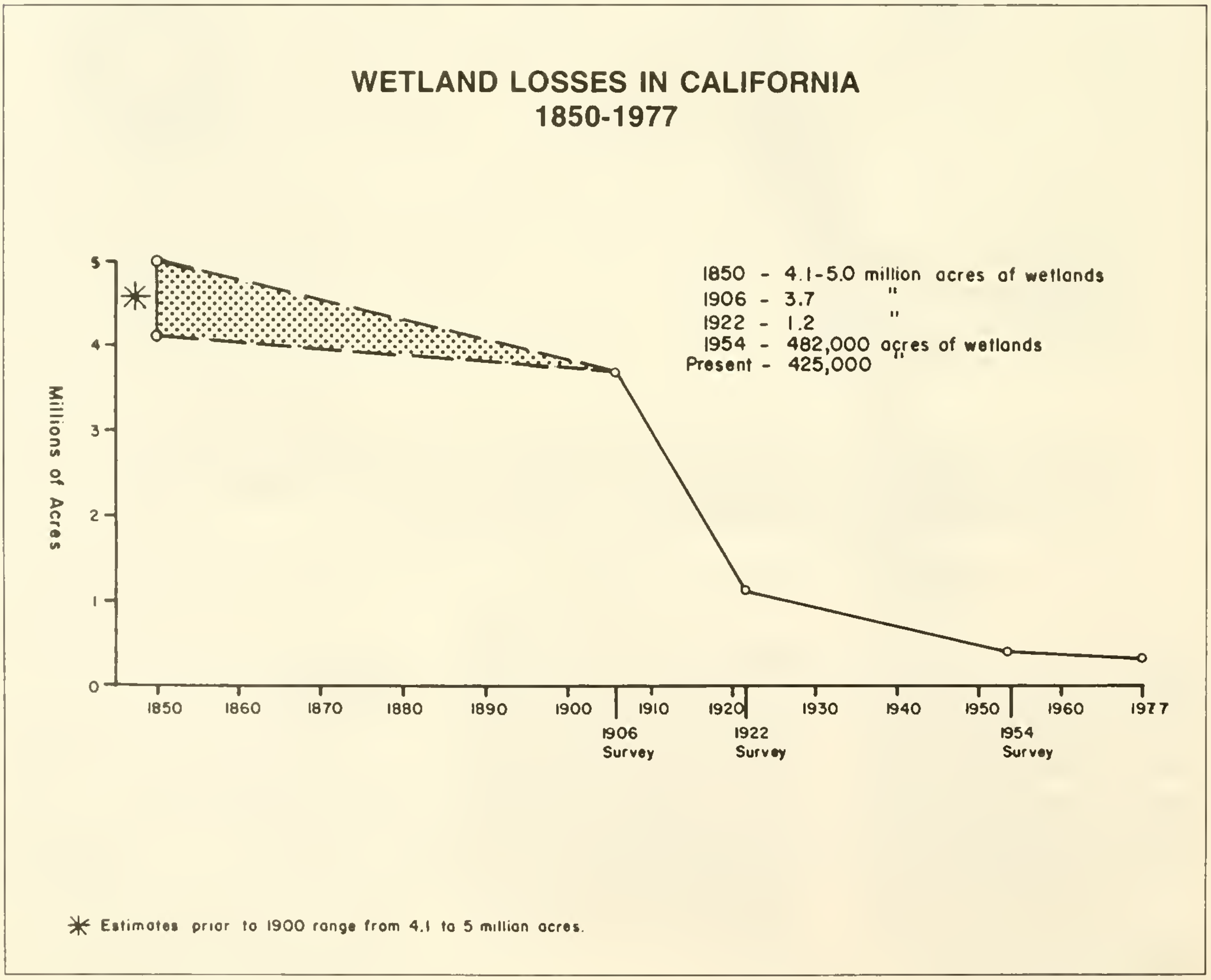


FIGURE 5

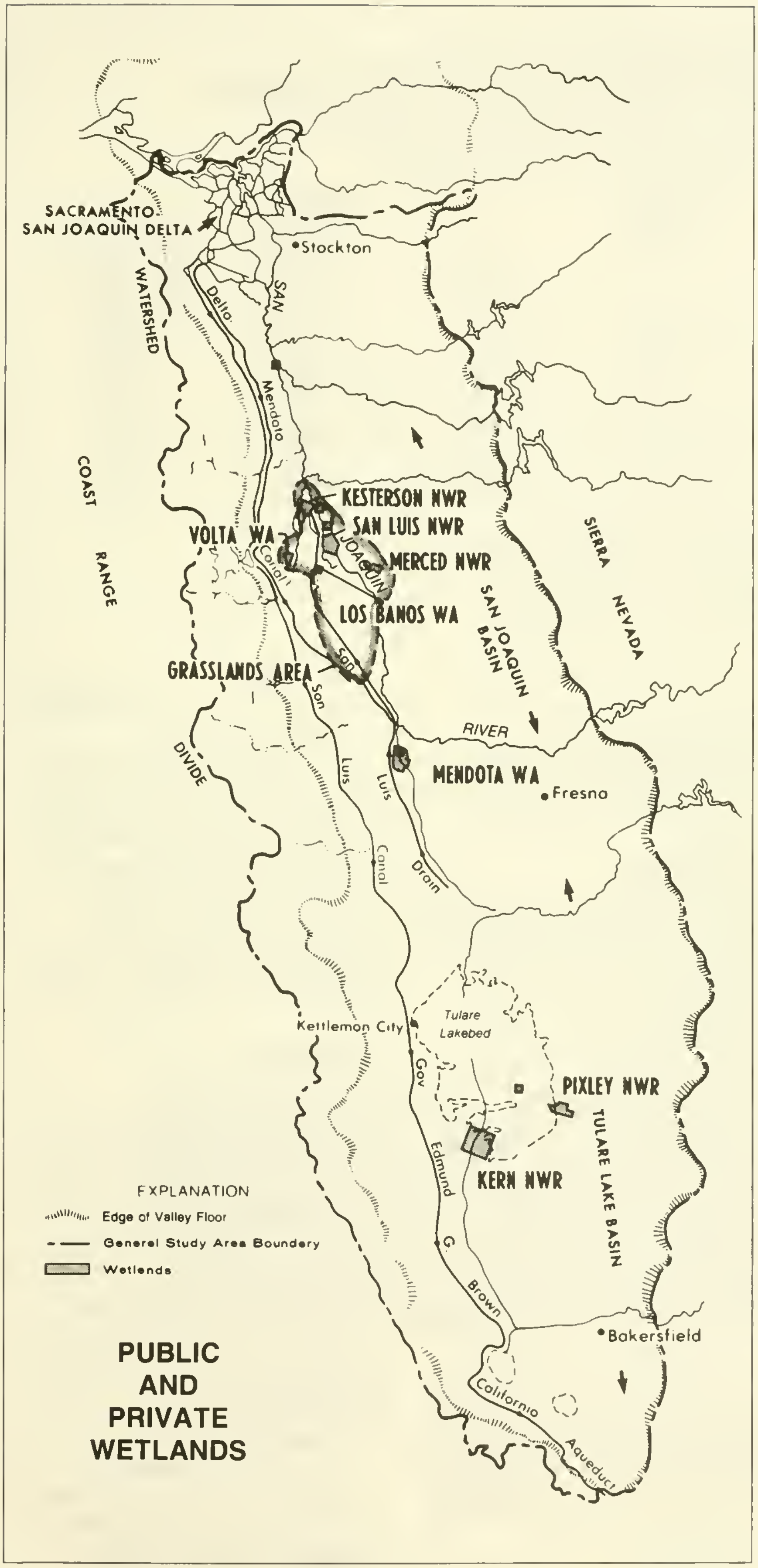


FIGURE 6

mately 47,000 acres) are presented in **table 3.** There are about 140,000 acres of private wildlife lands in the principal study area, many in the Grasslands area. Freshwater needs for private lands within the Grasslands (the largest contiguous block of wildlife lands in the valley) have been estimated at 195,000 acre-feet per year, of which 50,000 acre-feet is currently provided.

In addition to wetland habitat, migratory birds are also exposed to drainage water contaminants through agricultural evaporation ponds. These ponds are commonly used in the southern part of the valley. Recent data from studies by the Fish and Wildlife Service and the Department of Fish and Game have shown elevated levels of toxic and potentially toxic trace elements, including arsenic, boron, and selenium, in evaporation ponds in the Tulare Lake Basin. Elevated concentrations of these elements were found in fish and migratory birds and in aquatic plants and invertebrates that are important parts of their diets.

Recent laboratory research on selenium toxicity has shown reproductive and physiological impacts on adult mallards and adverse effects on growth and survival of ducklings. These effects occurred at dietary selenium concentrations much lower than concentrations in invertebrates in some evaporation ponds. The effects on fish and wildlife of elevated dietary concentrations of arsenic and boron are less well understood than are the effects of selenium. Ongoing toxicity studies address these and other concerns, including synergistic and antagonistic effects of trace elements on fish and wildlife.

Water Supplies and Needs for Federal and State Wildlife Areas in the San Joaquin Valley
(acre-feet per year)

Habitat[b]	Supply[a]: Freshwater[c]	Supply[a]: Agricultural Drainage Water[d]	Supply[a]: Total	Total Needed For Optimal Management	Freshwater Supply Deficit
Kern NWR	6,800	0	6,800	25,000	18,200
Kesterson NWR	3,500	8,000	11,500	20,000	16,500
Los Banos WA	6,160	12,200	18,360	25,000	18,840
Mendota WA	18,250	0	18,250	30,000	11,750
Merced NWR	13,900	350	14,250	16,000	2,100
Pixley NWR	0	0	0	6,000	6,000
San Luis NWR	0	15,300	15,300	19,000	19,000
Volta WA	10,000	0	10,000	16,000	6,000
Totals	58,610	35,850	94,460	157,000	98,390

[a]Water supply figures are averages of those volumes received (or estimated to have been received) during the late 1970's to mid-1980's.
[b]NWR - National Wildlife Refuge; WA - (State) Wildlife Area
[c]"Freshwater" refers to clean, reliable (firm) supplies, and includes: natural surface-water flows, developed water delivered via canals and other waterways, and pumped ground water.
[d]"Agricultural Drainage Water" refers to both subsurface (tile) drainage and surface (tail) drainage.

TABLE 3

Geology

Salinization and toxicity problems on the west side of the valley can be understood in terms of the geology of the Coast Range and the Sierra Nevada. **Figure 7** shows geologic cross sections through the central and southern parts of the western portion of the valley, illustrating the general structure of layered sediments that are hundreds of feet thick. The Corcoran clay layer, which lies at a depth of 400 to 600 feet below the land surface, is an important geologic feature that restricts the downward movement of ground water.

Soils on the west side of the valley tend to contain large amounts of soluble salts and trace elements, because they are derived from marine sedimentary rocks. Salinity and contaminant problems are most pronounced in these fine-textured soils and in the ground water on the west side of the valley. In contrast, the Sierran sand, which has its origin in the Sierra Nevada, contains ground water of good quality and is especially low in selenium.

Hydrology

The San Joaquin Valley includes two hydrologic basins -- the San Joaquin Basin, which drains to the Pacific Ocean via the San Joaquin River, and the Tulare Lake Basin, which is a closed basin except during periods of exceptionally high runoff.

Annual rainfall in the valley averages about 14 inches in the north and 5 inches in the south, providing a minor portion of the valley's total water supply. Additional water supplies average about 12 million acre-feet annually: 4.2 million from ground water, 4.2 million from surface-water runoff (mostly snowmelt from the Sierra Nevada), and 3.6 million imported from northern California through the Delta to the west side of the valley. About 95 percent of the total water use is for agriculture.

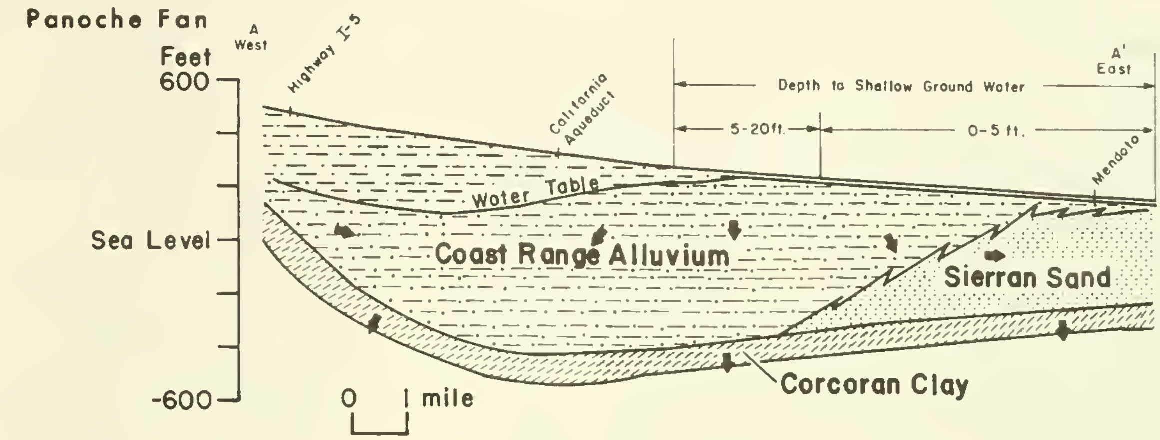
The quality of the water imported from the Delta is of lower quality than Sierra Nevada runoff but is generally much better than the quality of Coast Range streamflow or ground water on the west side of the valley. However, even the high-quality imported water carries a substantial salt load.

Substances of Concern

The Coast Range is the principal source of many potentially toxic natural elements found in valley drainage water. Relatively minor amounts of selenium and other trace elements are brought into the valley with imported water. Irrigation, evapotranspiration, and drainage of west-side soils mobilize, transport, and concentrate these natural elements — primarily in shallow ground water.

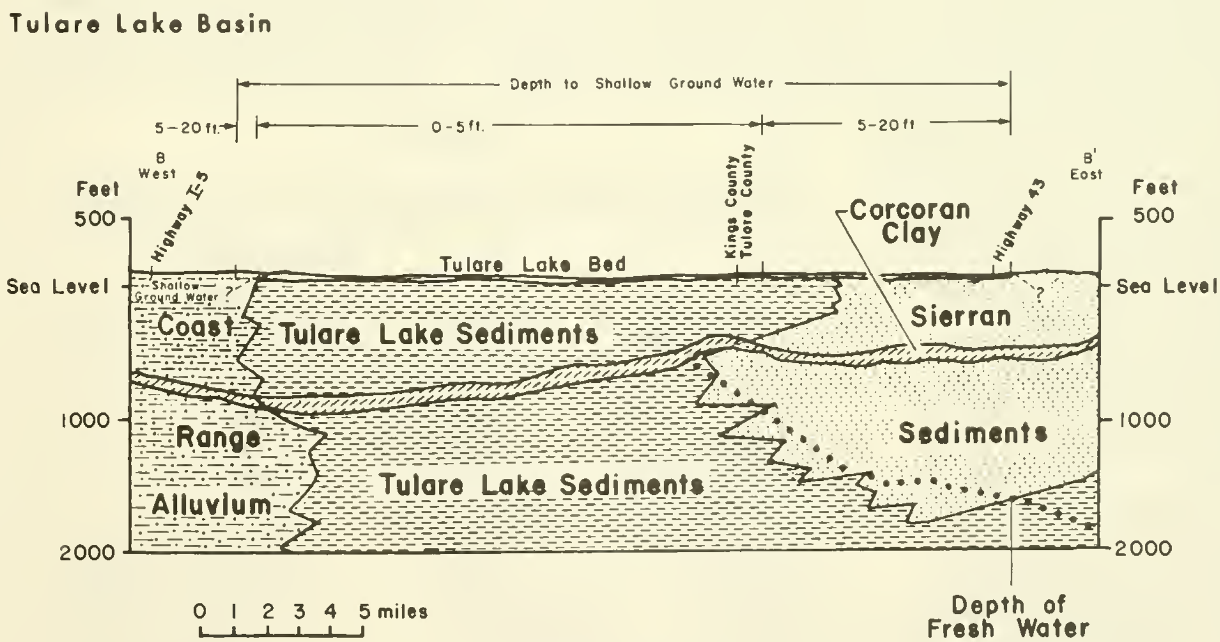
The phrase "substances of concern" refers to selenium and other toxic or potentially toxic substances such as arsenic,

GENERALIZED GEOHYDROLLOGIC CROSS-SECTIONS IN PANOCHE FAN AND TULURE LAKE BASIN (Locations Shown in Figure 3)



generalized direction of ground-water flow

Adapted from: Belitz, Kenneth, In Press. Hydrogeology of the regional flow system, central part of the western San Joaquin Valley, California. USGS Report and California Department of Water Resources, 1987, Map of Present and Potential Drainage Problem Areas.



After: Page, Ron, 1983 Geology of the Tulare Formation and Other Continental Deposits, Kettleman City Area, San Joaquin Valley, California, WRI Report 83-4000; and DWR 1987, Map of Present and Potential Drainage Problem Areas.

FIGURE 7

boron, chromium, mercury, molybdenum, and total dissolved solids. These substances are of concern because of their potential adverse effects on agricultural production, fish and wildlife resources, and public health. Toxicity problems associated with trace elements in drainage water are compounded by bioaccumulation and biomagnification through the food chain.

Table 4 summarizes the concentrations of selected trace elements from 40 water-sampling sites on the west side of the valley. Areas with the highest concentrations of selenium in soil are shown in **figure 8.** There is a general correlation between high concentrations of selenium in soils and high concentrations of selenium in ground water on the west side of the valley.

The Drainage Program, in conjunction with the Central Valley Regional Water Quality Control Board and Grassland Water District, has established a water-quality monitoring network in the Grasslands area, between Mendota and Gustine. **Figure 9** shows the locations of monitoring sites. Samples are analyzed for basic constituents and selected trace elements. These monitoring activities are modified periodically in response to information needs and to the activities or findings of other organizations. For example, the Department of Water Resources is developing an expanded surface-water study in the Grasslands area which will affect these ongoing monitoring activities.

In addition to trace elements, pesticides may pose a risk to public health and the environment. Although pesticides have rarely been detected above trace levels in subsurface drainage water, they have been observed at measurable levels in agricultural tailwater (field runoff). Commingling of tailwater and subsurface water is a common practice in portions of the San Joaquin Basin and in many areas in the Tulare Lake Basin. Commingled water that is or could become a problem because of pesticides or other organic contaminants is included in Program investigations.

Public Health

High levels of selenium detected in fish, wildlife, and plants raised concerns about potential health risks associated with drainage water. As a precaution, public health warnings have been issued several times during the last 2-3 years by the California Department of Health Services advising people to avoid or limit consumption of fish and waterfowl collected in the Kesterson Reservoir, Grasslands, and Tulare Basin areas.

In 1985, a scientific/medical committee established by the Merced County Health Department completed an assessment of potential health risks associated with Kesterson Reservoir. The assessment concluded that there was no evidence of toxic effects to residents of the Kesterson area. Because of the limited available data and information at that time, the committee recommended further environmental and public health monitoring throughout the planning process for Kesterson cleanup.

Since 1985, health surveys have been conducted of local residents, workers in the Kesterson refuge area, and foragers in the Kesterson and Grasslands areas. Samples of drainage water, ground water, air, vegetation, domestic animals, and wildlife have been collected to assess any potential public health problems. The Department of Health Services completed a report in mid-1987 presenting public health implications of elevated selenium levels in the valley, specifically Merced County and the area surrounding Kesterson National Wildlife Refuge. Investigative activities by various agencies were summarized and assessed in the report.

In general, the report found that studies to date have indicated no adverse health effects on local residents, but concluded that levels of selenium in fish, aquatic birds, and waterfowl were

TABLE 4

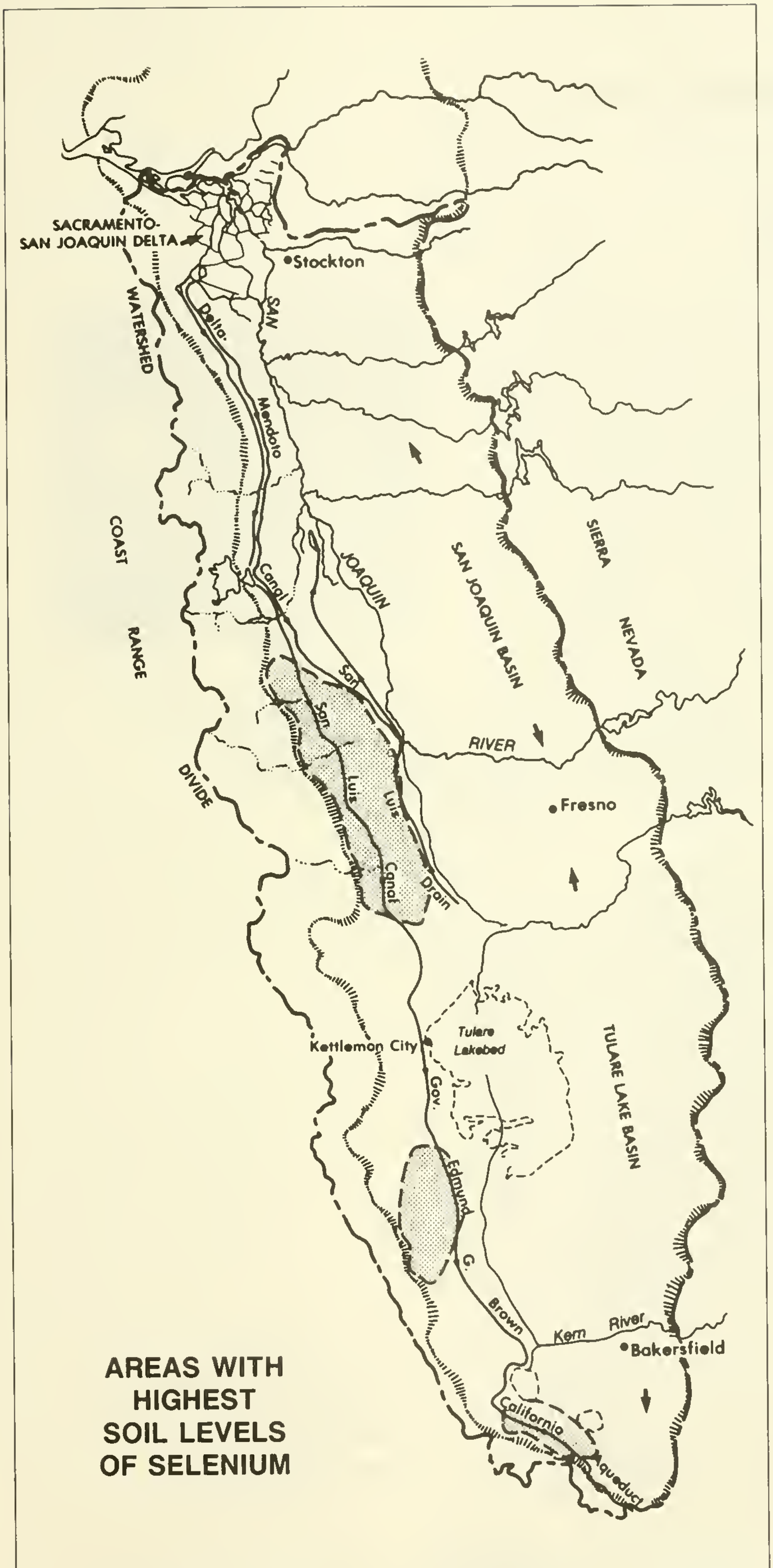
Drainage Water Concentrations of Trace Elements[a]

Constituent	Concentration (parts per billion) Minimum	Maximum	Median
Arsenic	< 1	50	< 1
Boron	40	84,000	6,500
Cadmium	< 1	4	< 1
Chromium	< 1	800	2
Copper	< 1	510	6
Iron	< 3	360,000	250
Lead	< 1	73	< 1
Manganese	< 1	9,000	80
Mercury	< 0.1	1.6	< 0.1
Molybdenum	< 1	1,500	13
Nickel	< 1	900	16
Selenium	< 1	4,700	25
Silver	< 1	10	< 1
Zinc	< 3	1,000	11

[a] Date collected by USBR and USGS during 1984-86 from 40 sites (observation wells, farm drain sumps, and collector drains) in the Federal water service area and Kings County

unsafe for unrestricted human consumption. Data on drinking water, livestock, animal products, and air particulates did not suggest a high level of exposure. However, selenium concentrations in soil and sediment from selected areas suggested potential sources of high exposure. Because of the limitations in existing data, the Department of Health Services has recommended further studies be conducted to make a conclusive assessment of potential health risks.

Additional investigations being undertaken for the Drainage Program include ethnographic surveys of high-risk populations in the Kesterson, Grasslands, and Tulare Basin areas. These surveys will assess the food consumption patterns of various local population groups, including foraging habits and locally grown food products that make up part of the diet of local residents. The expanded studies will include a survey of the general population outside the immediate area to provide data necessary to help assure protection of public health from potential adverse impacts associated with agricultural drainage water.



EXPLANATION

- Edge of Valley Floor
- General Study Area Boundary
- Highest 10% of Soil Selenium Values Measured

NOTE: The delineation of high-selenium areas is based on sampling and testing of soils from 297 sites throughout the San Joaquin Valley.

FIGURE 8

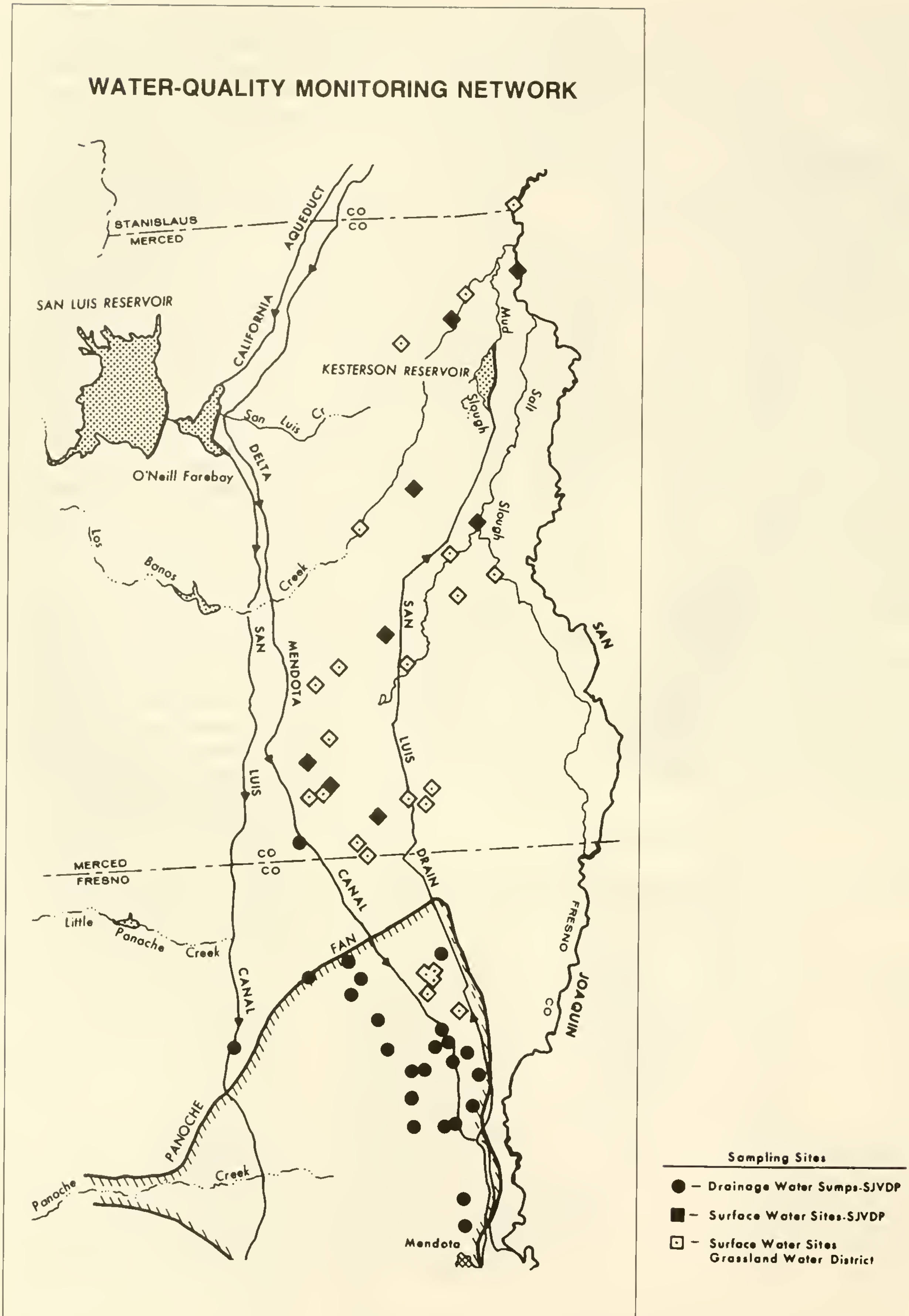

WATER-QUALITY MONITORING NETWORK
STANISLAUS
MERCED
CO
CO
AQUEDUCT
CALIFORNIA
SAN LUIS RESERVOIR
KESTERSON RESERVOIR
Mud
Slough
Salt
Slough
San Luis Cr
DELTA
O'Neill Forebay
Los Banos Creek
SAN
MENDOTA
SAN
LUIS
DRAIN
SAN
LUIS
CANAL
MERCED
FRESNO
CO
CO
CANAL
Little Panoche Creek
FAN
CANAL
FRESNO
CO
JOAQUIN
PANOCHE
Panoche
Creek
Mendota
Sampling Sites
— Drainage Water Sumps-SJVDP
— Surface Water Sites-SJVDP
— Surface Water Sites Grassland Water District

FIGURE 9

Programing Planning

The Program's planning process for developing solutions to agricultural drainage and drainage-related problems in the San Joaquin Valley involves four principal efforts: (1) Improving the data base, (2) developing analytical models and procedures, (3) identifying and screening potential management options, and (4) formulating and evaluating comprehensive area-specific plans. **Figure 10** shows the steps involved in the planning process. Throughout the planning effort, the Program is providing technical information on Program studies and activities to facilitate public understanding and involvement.

Planning Process

Data base. The Program, subject to available funds, is continuing to support critical research efforts that contribute substantially to solving drainage and related problems and are responsive to the time requirements of regulatory agencies, landowners, and resource managers. Current research is focusing on specific geohydrologic conditions in the valley, toxic effects of trace elements on fish and wildlife, potential drainage-related risks to public health, irrigation and drainage technology, and drainage water treatment.

Research that should be continued beyond the conclusion of the Drainage Program in 1990 will also be identified. A considerable volume of new data and information has been developed through Program investigations on bioaccumulation, biomagnification, and toxicity of drainage water substances in fish and wildlife. However, final results from some of these investigations, such as interactive effects of drainage water substances, will not be complete before the Program ends. Therefore, in some cases evaluations of potential solutions to drainage problems will have to be based on preliminary findings, trends, and projections.

Analytical models. A series of analytical studies is being conducted to relate economic and social factors to the physical and biological conditions in the valley. Economic studies are under way on management of drainage water residuals and on farm-level and regional-scale agricultural models. The economic studies involve:

- Describing irrigation water management and its relationship to crop yield, drainage volume, and drainage water quality (including contaminants and salt concentrations).
- Identifying economic and in stitutional factors that provide incentives for adopting different irrigation technologies.
- Determining consumptive and nonconsumptive economic values of fish and wildlife resources affected by agricultural drainage water, assessing the impact of drainage management options, and identifying mitigation measures.

Current social assessment efforts include compiling baseline data on social conditions in the drainage study area, such as:

- Demographic and socio-economic characteristics in the drainage problem area.
- Communities and subgroups in the population most affected by drainage and related problems.
- Criteria for determining the probable effects of management alternatives on the populations and subpopulations of the area.

Management options. Management options that have been identified to date include eight interrelated categories (discussed in next Chapter). These categories are: On-farm water management, fish and wildlife habitat management, shallow ground-water management, land use changes, drainage water treatment, reuse, and disposal, and regulatory and innstitutional changes.

As management options are identified, preliminary evaluation and screeninng are conducted. Options are evaluated using specific technical criteria, including the following:

- Effectiveness
- Risk assessment
- Environmental performance
- Institutional feasibility
- Economic efficiency
- Social impacts
- Irreversible or irretrievable commitment of resources

Effectiveness in addressing the four principal Program concerns (agricultural productivity, fish and wildlife resources, water quality, and public health) is evaluated in measurable terms, such as dollars of agricultural/recreational-related income, or acres in farmland or wetland habitat.

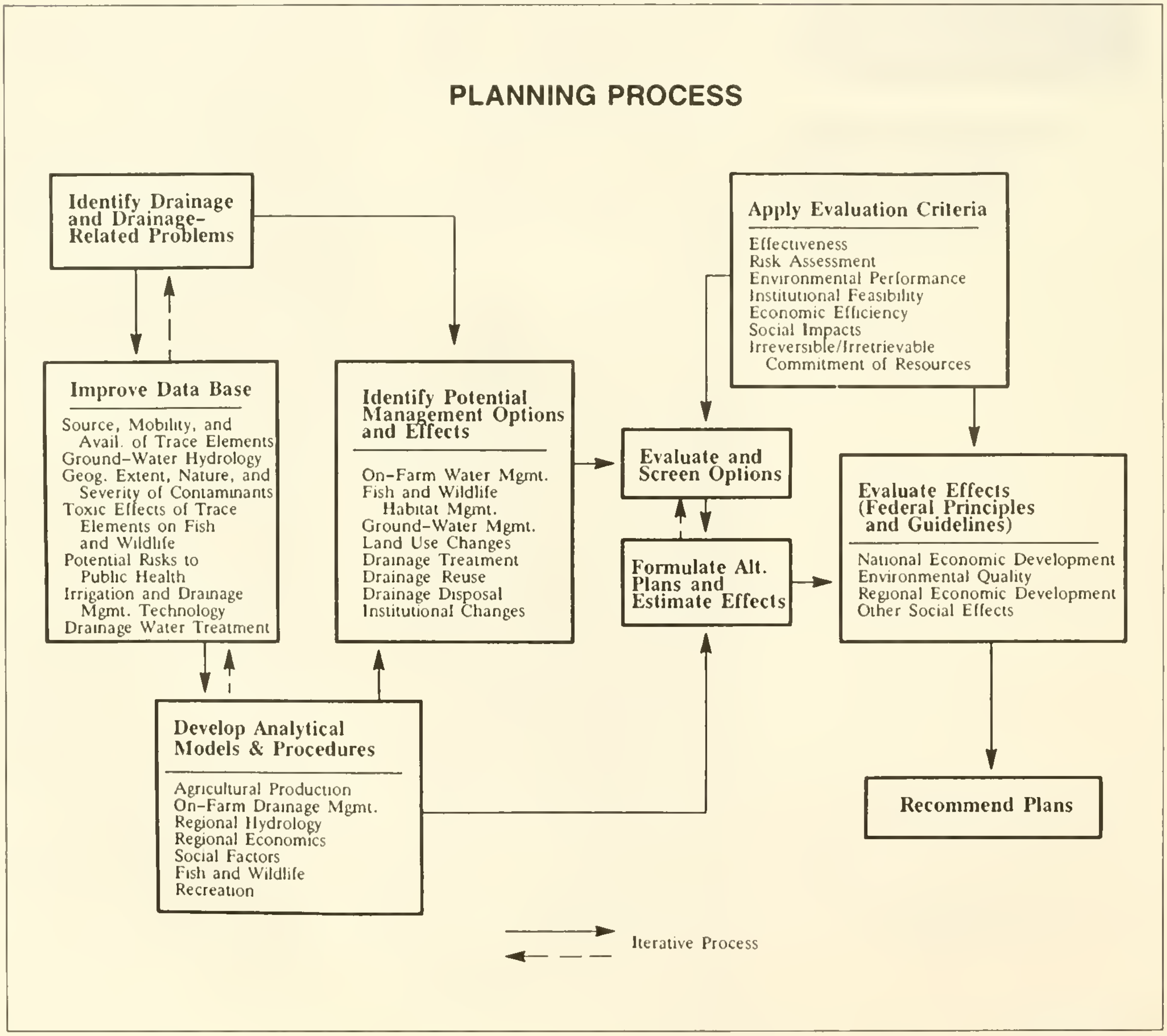


FIGURE 10

Risks are identified and quantified, where possible, with options evaluated in terms of potential risk to public health and the environment. The methods for assessing risks follow those in the Federal Principles and Guidelines for Water and Related Land Resources Planning (discussed further under Area-Specific Plans).

In evaluating environmental performance, options are analyzed for compliance with applicable Federal, State, and local environmental laws, regulations, and policies. The effects of options are assessed to determine their beneficial and adverse impacts on, among others: (1) Air quality, (2) soil quality, (3) surface- and ground-water quality, (4) fish and wildlife, (5) endangered species, (6) cultural resources, and (7) land use (such as farmlands, open space, wetlands, and flood plains).

With respect to laws, regulations, and policies, options are judged from two perspectives: (1) The feasibility of implementing an option within compliance of current laws and governmental authorities, and (2) the increased benefits (and associated costs) that would result from possible modification to policies, regulations, or laws. The costs to society of **not** modifying current institutional factors are also considered.

Economic efficiency is determined through a comparison of all benefits and costs, and options judged as efficient will be those that maximize net benefits. Economic effects are considered in terms of changes in resource uses, employment patterns, and income in the local community, region, and State that result from plan implementation and operation.

Social factors that act as "quality of life" indicators are considered in evaluating options. Such social factors include per-

sonal health and safety, comfort, perceived living conditions, the quality of community services, employment opportunities, and recreational opportunities.

The irretrievable or irreversible commitment of resources to any option or combination of options will be identified and avoided where possible. In cases where such commitments are unavoidable, they will be described in terms of their duration, location, and magnitude, as well as social, economic, and environmental effects.

Area-Specific Plans

Alternative plans will be developed for each of five subareas within the principal study area, as shown in **figure 11.** These subareas have been delineated on the basis of hydrologic considerations, political boundaries, current drainage practices, and/or the nature of drainage-related problems. Subarea boundaries may need to be redefined during the planning process to facilitate the best combinations of alternative plans.

In developing management plans for specific subareas, the Program is using multiobjective planning techniques guided by the Federal **Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies.** The planning objectives adopted by the Program emphasize (1) National economic development and (2) environmental quality, with these objectives considered to be of equal importance.

The Program will utilize the four accounts established in the Principles and Guidelines to display the effects of alternative plans. The four accounts are:

- National Economic Development, which shows changes in the economic value of the national output of goods and services.
- Environmental Quality, which shows effects on ecological, cultural, and aesthetic attributes of natural and cultural resources that cannot be measured in monetary terms.
- Regional Economic Development, which shows the regional economic effects, including income transfers and employment effects.
- Other Social Effects, which shows urban and community impacts and effects on life, health, and safety.

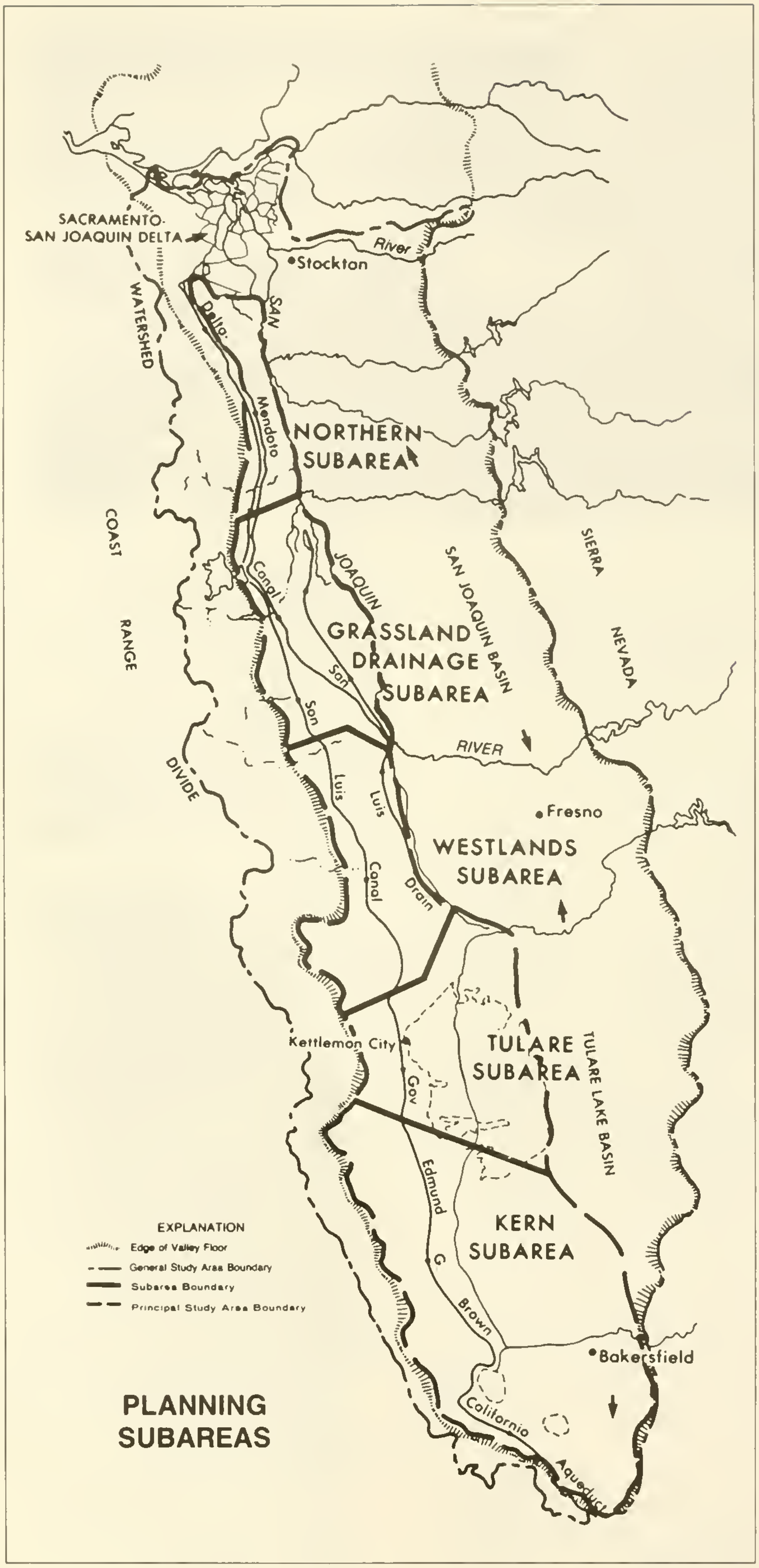


FIGURE 11

Using an iterative process, alternative plans are formulated, evaluated, and refined. With each iteration, plan elements become more detailed and alternatives more specific. The process results in the combining of complementary options into comprehensive plans that best satisfy the planning objectives.

Public Information and Involvement

Information developed from Program investigations is being made available in a variety of technical reports, scientific manuscripts and articles, status reports, and other informational materials. Beginning in 1988, the Program will conduct a series of public meetings and workshops, with the objective of involving affected and interested individuals and organizations in the formulation of comprehensive management plans. These meetings and workshops will be sponsored by the Program's Citizens Advisory Committee, which provides guidance for public involvement activities. The Citizens Advisory Committee, representing a broad spectrum of drainage-related interests and viewpoints, is involved in review and evaluation throughout the planning process.

Management Options

The focus of the Program planning effort during the next 2 years will be evaluation of both short-term and long-term drainage water management options, and formulation and analysis of comprehensive management plans. Potential management options identified to date include a broad array of both structural and nonstructural approaches that are being considered in eight interrelated categories:

- On-Farm Water Management
- Fish and Wildlife Habitat Management
- Shallow Ground-Water Management
- Land-Use Changes
- Drainage Water Treatment
- Drainage Water Reuse
- Drainage Water Disposal
- Regulatory and Institutional Approaches

On-Farm Water Management

Opportunities exist today on individual farms and within water districts throughout the drainage problem area to reduce the amount of irrigation water applied and, thereby, reduce the total volume of drainage water produced. For example, it has been estimated by the University of California that improved irrigation techniques could reduce total drainage water by as much as two-thirds. Such volume reductions could substantially decrease drainage treatment and/or disposal costs.

On-farm options to reduce drainage water volumes have been identified by the Agricultural Water Management Subcommittee of the Interagency Technical Advisory Committee in an October 1987 report. The subcommittee listed numerous irrigation practices and technologies having high potential for drainage reduction. Timeframes were also identified for implementing various actions for short-term (0-2 years), intermediate (2-5 years), and long-term (5-10 years).

Among the actions recommended by the subcommittee for on-farm drainage reduction were:

- Managing the shallow groundwater table to satisfy a portion of the crop water requirement.
- Precise scheduling of irrigation using evapotranspiration data.
- Separating tailwater and subsurface drainage.
  - Recirculating tailwater for reapplication.
  - Reusing subsurface drainage water where possible.
- Improving the uniformity of irrigation water application.
  - Using trickle irrigation systems.
  - Using low-pressure or modified continuous-move sprinkler systems.
  - Using drip methods of irrigation.
  - Using surge control systems in furrow irrigation.

- Using controlled volume methods in furrow irrigation on sloping fields.
- Level-basin irrigating where possible.
- Sprinkle irrigating for pre-irrigation and seed germi nation.

Because of differences in local soil and ground-water conditions, the appropriateness, practicality, and cost-effectiveness of specific practices vary within individual fields and from farm to farm. Also, in some areas seepage flows from conveyance and collector systems, natural water channels, reservoirs, and holding ponds contribute substantial amounts of water to the regional ground-water aquifer and could, in some situations, largely negate the effect of on-farm water management measures.

Field research and demonstration efforts are investigating the relative effectiveness of various on-farm management options. The potential use of economic and other incentives and disincentives to promote on-farm water conservation are also being investigated. The results of these studies will increase the ability of farm and water district managers to select appropriate options.

Current Program activities include development of an agricultural production model of irrigated crops under saline conditions. The model is based on existing conditions of soil salinity, irrigation rates, and crop yields in the Broadview Water District. The model will incorporate irrigation and recycling opportunities typically available to valley farm operations and analyze the resulting costs and income to growers. The relationship between various on-farm management practices and the resulting production of subsurface drainage water is also being examined. This work incorporates potential effects of on-farm decisions into an agricultural production model for the Grasslands area.

Fish and Wildlife Habitat Management

Potential actions that could be taken to protect, restore, and enhance fish and wildlife resources affected by agricultural drainage include:

- Habitat Restoration: Restore aquatic, riparian, wetland, and other habitats in the San Joaquin Valley that have been contaminated by agricultural drainage water.
- Habitat Protection: Through acquisition, financial incentives/disincentives, or regulation, provide additional public access to and facilities for fish and wildlife habitat and protect existing and newly established public and private wildlife areas.
- Water Storage in Wetlands: Use wetland, grassland, and riparian areas as fall, winter, and spring water storage areas and release stored water during the summer for instream and downstream nonconsumptive and consumptive uses.
- Sequence of Water Delivery: Deliver imported freshwater to rivers, streams, wetlands, and other wildlife habitats prior to providing it to agriculture.

Personnel assigned to the Program from the Department of Fish and Game and Fish and Wildlife Service, and personel from other organizations such as the University of California are currently conducting several studies to define fish and wildlife restoration, mitigation, and enhancement needs and opportunities; to develop and evaluate specific measures to address such needs and opportunities; and to assess the effects on fish and wildlife of other actions being considered to solve drainage and drainage-related problems.

Shallow Ground-Water Management

Managing shallow ground-water levels on a district or regional basis (rather than on an individual farm basis) may provide effective means to solve drainage problems in some high water table areas of the valley. For example, lowering and maintaining the water table to a depth of 10 or more feet in irrigated areas would greatly diminish the need for

on-farm drains. Possibilities are being investigated to establish and implement provisions for district/regional ground-water management and conjunctive use of ground water and surface water. This would require extensive cooperation by involved interests at all levels and will require greater understanding of ground water on the west side of the valley.

Several studies have been completed or are under way by the U.S. Geological Survey which are providing information on ground-water conditions and movement in the study area. These include:

- Valley-wide evaluation of ground-water quantity and quality as part of the Regional Aquifer Systems Analysis program.
- Detailed evaluation of ground-water quantity and quality in the Panoche Fan area, including computer modeling of ground-water movement in and adjacent to the Panoche Fan/Cantua Fan area.
- Solute (salt and trace element) transport evaluation as part of the Panoche Fan/Cantua Fan modeling.
- Documentation and evaluation of shallow (less than 20 feet from the surface) ground-water quantity and quality on a regional and local scale, including evaluation of agricultural drainage water chemistry.

These studies will provide improved knowledge of ground-water characteristics necessary for the design and evaluation of options for managing ground water to remedy drainage and related problems.

The Drainage Program is conducting a demonstration project for drainage flow reduction at sites on farms in the Panoche Drainage District, Broadview Water District, and Firebaugh Canal Company. The objectives of the project are to demonstrate the effectiveness of controlling water table levels and managing salt balance and leaching requirements. Both modified drainage systems and control sites are being monitored during a 2-year study period.

Also under way are studies by local water districts evaluating the relationships between irrigation practices, soil characteristics, and shallow ground-water movement on drainage water quantity and quality in the Panoche Fan.

Land-Use Changes

Irrigated field crops are grown on nearly all of the agricultural lands within the problem area. Several options for change from intensive irrigation of cropland to other uses show promise in helping to solve drainage and related problems. Those being investigated are: (1) Changing cropping patterns to crops that are more salt tolerant and/or require less water, (2) converting cropland to wildlife habitat, (3) converting cropland to open-space areas, and (4) idling irrigated cropland in areas with high levels of selenium or other toxic elements.

Changes in cropping patterns. One possibility for growers with saline soil is to select salt-tolerant and/or low-water-use crops. Considerable research is being conducted under several Federal, State, local, and university programs to identify and breed salt-tolerant and drought-tolerant crops. For example, the Agricultural Research Service and the University of California conduct plant breeding research programs. Plant breeding directed toward improving tolerance to stress factors primarily involves salinity. These research programs also address drought tolerance indirectly because of the relationship of salinity and soil/plant/water relationships.

Conversion to wildlife habitat. Conversion of irrigated lands to wildlife habitat could aid in drainage water management and restoration of wildlife habitat. Upland areas could be converted to mixed hardwood or grassland habitat and lowlands to wetland or riparian habitat. Studies now under way will allow identification of candidate lands and evaluate the possibilities for and effects of conversion.

Conversion to open-space areas. Another possible option is conversion of drainage-impaired agricultural lands to open space or recreation areas for day-use offering picnicking, outdoor sports areas, and nature observation and study. Generally, the problem area has extensive cropland with very little recreation and open areas devoted to public use. Land is owned almost entirely in large private tracts. The creation of islands of open public lands on what is now drainage-impaired cropland could aid in reducing drainage water volumes, provide public recreation opportunities, and benefit wildlife by restoring habitat.

Idling irrigated cropland. Some areas of the valley have unusually high concentrations of certain trace elements in the soils and shallow ground water. Parts of Panoche and Cantua Fan areas west and south of Mendota have been identified as soil and ground-water areas high in selenium. Ceasing irrigation on some acreage within these areas could help reduce drainage volume and improve the quality of remaining drainage water. Further information is required to evaluate this option, including projected reductions in drainage water, economic benefits and compensation that might be involved, distance of affected areas from potential treatment facilities,

and possible methods to restore these lands to agricultural production or other beneficial uses.

Drainage Water Treatment

Worldwide, research, development, and the application of various treatment processes for saline and brackish water have been under way for many years to produce drinking water supplies. In addressing the particular drainage problems of the San Joaquin Valley, Program agencies and the Interagency Technical Advisory Committee have examined numerous treatment processes specific to removal of total dissolved solids, selenium, and other substances of concern in valley drainage water. Of those evaluated to date, the eight processes listed in **table 5** and discussed here have demonstrated the best potential for possible use in the valley.

- **Bacterial treatment.** Design work is currently under way for a prototype bacterial treatment plant to be constructed near Mendota. The plant is being designed by Binnie California, Inc., for Westlands Water District. Extensive testing of the process at pilot scale, conducted in 1985-86, received funding through Westlands Water District, other agricultural interests, State Water Resources Control Board, Department of Water Resources, and Department of Fish and Game. Objectives of this research were: (1) To determine treatment costs

TABLE 5
Development Status of Selenium Treatment Processes

Process (Investigator)	Method	Development Stage: Laboratory Bench	Pilot Mini-Batch	Pilot Prototype	Se Level in Treated Effluent (ppb)[a]	Estimated Cost ($ per acre-ft)[b]
Bacterial (Binnie Calif.)	Biological			X	5-10	150-300
Iron filings (Harza Eng.)	Adsorption			X	10-50	25-250[c]
Iron hydroxide (USBR)	Chemical		X		1[d]	100-150
Algal/bacterial (UC Berkeley)	Biological		X		1[d]	75-150
Selective Resins (Boyle Eng.)	Ion Exchange	X			-	-
Volatilization (UC Riverside)	Biological		X		-[e]	-
Chemical Physical attenuation (UC Riverside)	Chemical	X			-	-
Membrane separation (USBR/DWR)	Reverse Osmosis			X	10-20	980 - 1,220

[a] Tests based on San Luis Drain water or equivalent (Se) at about 350 ppb.
[b] For 10 million gallon per day plant. Based on incoming water volume.
[c] Depending on projected life of iron filing-beds, contact time, and removal efficiency required
[d] Based on laboratory bench tests only
[e] Previous tests showed 35% removal of selenium in a 37-day treatment period for soils from the Panoche Fan area

- under varying operational conditions, (2) to test the effectiveness of the process using drainage water with high total dissolved solids and high selenium concentrations, and (3) to evaluate whether selenium and other usable byproducts can be recovered after treatment. Currently, the Drainage Program is funding laboratory research by the University of California, Davis, on the theoretical basis of the process.
- **Iron-filing adsorption.** Pilot-plant studies were completed for Panoche Water District in 1986 on the adsorption process patented by Harza Engineering Company. The process uses columns of activated iron filings to remove selenium (and/or metals such as zinc, lead, chromium, and arsenic) from agricultural drainage water. The Drainage Program is currently funding further studies by Harza to resolve questions which remain prior to large-scale application of the process. These questions involve: (1) Verifying the adsorption process which makes selenium removal possible, and (2) identifying and overcoming conditions which cause the iron filings to clog in the columns.
- **Iron-hydroxide precipitation.** Under Program sponsorship, field tests are being conducted near Mendota on an iron-hydroxide process for treating selenium. The investigations are under way by staff from the Bureau of Reclamation's Engineering and Research Center in Denver. Preliminary laboratory tests indicate that a high level of selenium removal is possible using iron hydroxides. Work currently involves expansion of the tests at the laboratory and field level to demonstrate the technical and economic feasibility of the process for removal of selenium and other trace elements from agricultural drainage water.
- **Microalgal/bacterial.** Laboratory bench studies completed by UC Berkeley in 1986 showed that selenium levels could be reduced in drainage water using microalgal-bacterial processes. The Drainage Program is currently funding continued work to develop high-rate microalgal ponds. The next step in the research is laboratory and field-level studies necessary for a detailed engineering evaluation of the process and preliminary design of a pilot plant.
- **Ion-exchange resins.** Preliminary bench-scale studies to screen various ion-exchange resins for the selective removai of selenium from drainage water were recently completed for the Drainage Program by Boyle Engineering Corporation. Tests were conducted for several resins with a range of selectivity. Each of the resins was tested to determine if it is selective enough to treat selenium in drainage water without being so selective that it requires an excessive amount of chemicals for regeneration. Other factors considered include the kinetics and resin exchange capacity to treat sufficient amounts of water before regeneration, the cost to manufacture the resins in large quantities, and the total costs to treat drainage water.
- **Volatilization process.** UC Riverside is investigating the use of fungi in transforming selenium to a relatively low-toxic gaseous state. This volatilization process, which removes selenium from water or soils and recycles it into the atmosphere, is a natural biological process common in all ecosystems. Tests of three fungal species conducted last year on Panoche Fan soil samples demonstrated that 35 percent of the selenium in surface soils could be volatilized in 37 days if provided with an adequate carbon source. UC is currently conducting research for the Kesterson Program and the Drainage Program, respectively, to determine the potential of the process to aid cleanup efforts at Kesterson Reservoir, and as a treatment process for on-farm evaporation ponds. Work for both programs involves identifying optimum conditions for biovolatilization of selenium.
- **Chemical/physical attenuation.** As selenium moves through the soil profile, it speciates and adsorbs at various rates and degrees depending on soil chemistry. Studies are currently being conducted for the Drainage Program by UC Riverside to test the degree to which selenium emissions can be attenuated. These studies involve constructing a series of experimental soil columns and using a variety of chemical and physical techniques to identify the characteristics of soil which maximize selenium attenuation. If successful in laboratory studies, field demonstrations will be conducted.
- **Reverse-osmosis desalting.** The reverse-osmosis process involves forcing water through a membrane filter that separates salts from the water. Pretreatment of the feedwater to minimize membrane clogging (or "fouling") is essential for effective reverse-osmosis operation. Extensive testing of the reverse-osmosis process was conducted by the Department

of Water Resources at its Los Banos demonstration desalting facility from 1982 to 1986. Objectives of the desalting facility included demonstrating the effectiveness of various pretreatment processes and the potential use of salt-gradient solar ponds to offset high energy requirements of the desalting plant. While the reverse-osmosis process has proven highly effective in removing total dissolved solids (salts) and trace elements such as selenium from drainage water, the process is extremely costly. According to a study conducted for the Drainage Program by CH2M Hill in 1985, costs would range from $1,150 to $1,280 per acre-foot of treated (product) water.

Drainage Water Reuse

Theoretically, drainage water could be reclaimed for a wide variety of uses in addition to agricultural reuse, including municipal and industrial water supplies, power production from salt-gradient solar ponds, aquaculture, silviculture, water supplies for wildlife areas, instream flows for fisheries and other uses, and recreation. All of these uses, however, would require removal of certain pollutants and/or toxic elements and would generally involve expensive treatment processes.

Preliminary studies have shown that municipal reuse of agricultural drainage water is unlikely because of the high cost of treatment. Of the potential industrial uses, powerplant cooling would likely require the least expensive treatment. However, the demand and the amounts required for powerplant cooling would be small compared to the total volume of drainage water generated.

Salt-gradient solar ponds offer the possibility of using drainage water salts in the production of electrical energy. Although some research has been done and solar ponds have produced electrical energy, use of drainage water is still considered experimental. The physical and chemical characteristics of the saline water will influence the chances of successful use in any specific area.

While some valley subsurface drainage water may be of suitable quality for use as a water supply in the commercial cultivation of fish or shellfish (aquaculture), public concerns about potential environmental and health risks would likely prevent general use of untreated drainage water for this purpose.

The use of agricultural drainage water for silviculture appears to be promising. Silviculture involves cultivation of salt-tolerant trees to reduce the volume of drainage water and to produce tree biomass as a potentially marketable commodity. Currently, the Drainage Program is providing funds for research involving agroforestry plots on 122 acres in the San Joaquin Valley. These demonstration plots, planted in 1985-86, are managed by individual farmers and are being monitored by the Department of Food and Agriculture and the Soil Conservation Service. In addition to Drainage Program agencies participating in the work, other agencies involved to date include the State Water Resources Control Board, the California Association of Resource Conservation Districts, California Department of Forestry, University of California at Davis, and California State University at Fresno. Current work involves: (1) Selection, testing, and propagation of salt-tolerant plant species from existing demonstration plots, (2) development of an economic model for production and marketing of tree biomass, and (3) investigation of the use of agroforestry sites by wildlife.

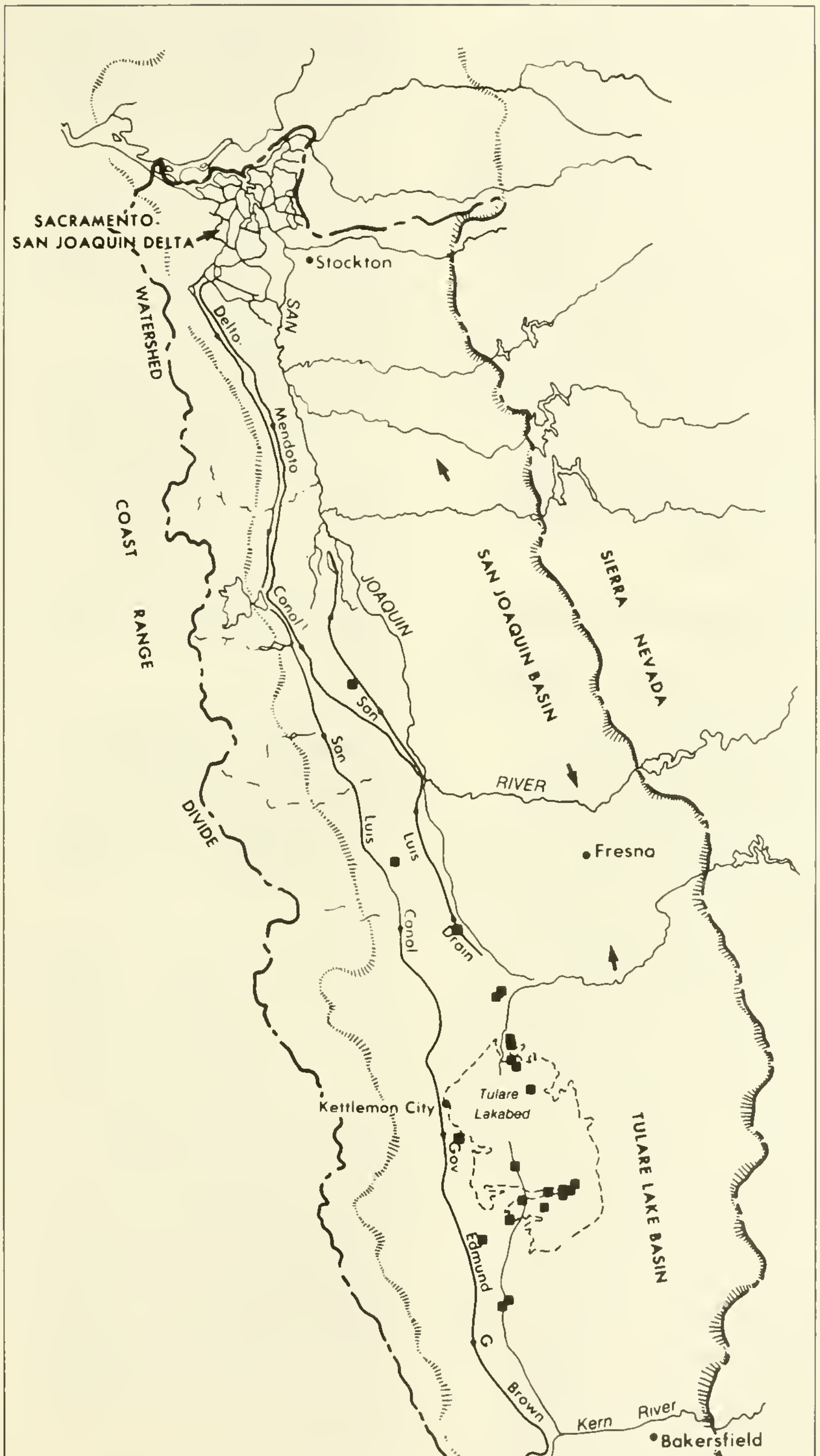
During the last few decades, agricultural drainage water has been used for fish and wildlife habitat, instream flow, and recreation in many rivers, streams, wetlands, grasslands, and evaporation basins throughout the San Joaquin Valley. However, food-chain bioaccumulation and biomagnification of selenium and other substances of concern from subsurface drainage water resulted in the severe environmental problems at Kesterson Reservoir. Because of toxic and potentially toxic properties and high salinity levels, much of the valley drainage water would be unacceptable without treatment for fish and wildlife, instream flow, or recreation.

As the Program's studies progress, consideration will be given to all possibilities for reuse of agricultural drainage water. In most cases, additional technical, environmental, and economic information must be developed before reuse options can be evaluated as part of comprehensive drainage management plans.

Drainage Water Disposal

Several potential sites for disposal of drainage water or treatment byproducts have been investigated for the Program. Preliminary screening by Brown and Caldwell Consulting Engineers included sites along the Pacific coast and in San Francisco Bay, Sacramento-San Joaquin Delta, San Joaquin River, western San Joaquin Basin, Tulare Basin, Carrizo Plain, Kettleman Hills, and Mojave Desert.

In the screening process, each geographic area was evaluated to eliminate unsuitable drainage-water disposal sites on the basis of biological, physical, geologic,



EVAPORATION PONDS IN THE SAN JOAQUIN VALLEY

FIGURE 12

EXPLANATION

Edge of Valley Floor

General Study Area Boundary

Evaporation Pond

hydrologic, and hydraulic criteria. Sites in each area were then ranked on the basis of technical, regulatory, economic, environmental, and legal factors. Very few sites remained as "potentially suitable" following the screening.

Subsequent to completion of the screening, Program management and advisory committees directed that investigative and planning efforts focus on in-valley solutions to the drainage water disposal problems. No studies of out-of-valley disposal of drainage water are planned to be conducted by the Program.

Currently, three in-valley disposal options are being evaluated: (1) Evaporation ponds, (2) deep-well injection, and (3) discharge to the San Joaquin River.

Evaporation ponds. Evaporation ponds are presently a common means of drainage water disposal in the valley. There are now 24 pond systems covering a total of approximately 6,700 acres **(see figure 12),** and many more evaporation ponds are being planned, especially in the southern part of the valley. The Central Valley Regional Water Quality Control Board has received applications for ponds covering about 10,500 additional acres, and the Board has projected that acreage requested for ponds could double in the next 5 to 10 years.

Two potential problems in expanding use of evaporation ponds are ground-water degradation from pond leakage and adverse effects of contaminants in the stored water on wildlife, especially migratory aquatic birds. Various State and Federal agencies, the University of California, and local water districts and individuals are working together to provide technical information needed for development of pond design and operational guidelines that will be technically, economically, and environmentally acceptable.

Two other important considerations in the use of evaporation ponds are the substantial land requirement (approximately 10-20 acres of pond for each 100 acres of drained land) and the ultimate problem of disposal of accumulated salts.

Deep-well injection. Deep-well injection has been used for many years by the oil and gas industry in the San Joaquin Valley for disposal of oil-field brines in very deep geologic formations, usually several thousand feet underground.

An appraisal-level study conducted for the Program in 1986 by URS Corporation concluded that deep-well injection of agricultural drainage water may have merit and warrants additional investigation, noting the need for pilot studies to determine feasibility. Westlands Water District has developed plans for a prototype injection well near Mendota. The Drainage Program will closely observe the Westlands tests and use the information developed in further evaluation of this option.

Disposal to the San Joaquin River. Currently, about 77,000 acres of farmland on the west side of the valley have subsurface drainage systems that eventually discharge into the San Joaquin River. The continuation of drainage discharge to the river will depend on water-quality objectives adopted by the Central Valley Regional Water Quality Control Board through modification of the San Joaquin River Basin Plan. These objectives will serve to prescribe the total load of salts and trace elements (selenium, boron, and molybdenum) that can be discharged from farm drains into surface-water bodies.

Institutional Changes

Certain types of institutional change could play a significant role in solving agricultural drainage and related problems. Existing institutional arrangements are currently being analyzed to determine how changes in laws, policies, regulations, markets, or legal entities could contribute to problem solutions.

Potential institutional changes to promote water conservation include water transfers, tiered (block) water pricing and/or drainage charges, and expansion of local or regional water authorities. Water transfers could offer incentives for conservation by allowing the sale of conserved water for profit. Under tiered water pricing local districts would charge higher prices for successive units of water. Examples of the expansion of water authorities could include creation of drainage districts, ground-water control districts, or total water management districts. The types of institutional changes considered by decisionmakers will depend on a number of interrelated factors, including potential agronomic, economic, environmental, and political effects.

In recent years, California has enacted legislation to facilitate water transfers, but a number of legal questions and issues remain regarding transfer of water developed by the CVP. Questions concern: (1) Legal interpretation of the "appurtenancy" provision of Reclamation law which may permanently attach water rights to a particular tract of irrigated land, (2) possible profit-sharing among buyer, seller, and federal government, and (3) allowable water transfers consistent with authorized water project purposes and service areas.

Tiered water pricing and/or drainage fees could serve as incentives for water conservation and encourage economical use of water. However, more information is needed before estimates of reduced water use can be made.

Regional authorities could be established to facilitate drainage management. Drainage districts could be established to manage, treat, and dispose of drainage water, as appropriate. Ground-water districts could manage drainage and ground-water conditions through planned and controlled pumping. A total water management entity could provide comprehensive surface-, ground-, and drainage water management. Authorities such as these could address such issues as drainage management financing and cost apportionment.

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